Soil Survey Manual

Soil Survey
Division Staff

United States
Department of
Agriculture

Soil Survey Manual

by

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Division Staff

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Soil Survey Manual Introduction

The Soil Survey Manual provides in a single volume the major principles and practices needed for making and using soil surveys and for assembling and using data related to them. The Manual is intended primarily for use by soil scientists engaged in the classification and mapping of soils and in the interpretation of soil surveys. Although the Manual is oriented to the needs of those actively engaged in preparing soil surveys for publication, workers and students who have limited soils experience or are less familiar with the soil survey process also will be able to use the information.

The Manual focuses on the major concerns of the members of the National Cooperative Soil Survey, a cooperative undertaking of the United States Department of Agriculture and an agency of each of the States: commonly, the State agricultural experiment station of a State's land-grant university. Other agencies—local, State, or Federal—cooperate under special agreements. The original Federal authority for the soil survey of the United States is contained in the record of the 53rd Congress, chapter 169, Agricultural Appropriation Act of 1896. The authority was elaborated in Public Law 74-46, the Soil Conservation Act of April 27, 1936, and again in Public Law 89-560, Soil Surveys for Resource Planning and Development, September 7, 1966. The Manual is the primary reference on principles and technical detail for local, State, and Federal contributions to soil surveys authorized under these acts. The term "the Soil Survey" is used in the Manual to refer to the National Cooperative Soil Survey.

It is hoped this third edition of the Manual will be as universally useful as were the first and second editions. Many professional people engaged in other aspects of soil science and in other disciplines have used earlier editions of the Manual as a reference. Soil Scientists concerned with soil surveys in other countries have used them as well. Teachers have used the earlier editions both as texts and as references for students. This third edition retains those attributes of the Manual that have made it useful to many groups without deviating significantly from its primary

purpose of serving the needs of soil scientists in the field.

Except for isolated passages, this edition of the Manual has been rewritten. Since the second edition (1951) was printed, a new soil taxonomy has been prepared and adopted. New and more intensive uses of soils have dictated changes, and advances in soil science as well as in related disciplines have provided new and more refined concepts and techniques. The increased use of soils for purposes other than farming has prompted new interpretations, more collaboration with professional people of other disciplines, and more adaptation of soil surveys to the concepts of other disciplines. These and other changes of two decades of work have made major revision of the Manual essential. This edition retains the practice of defining terms and concepts within the context of the explanatory text. A glossary is not included; to find definitions, explanations, and uses of specific terms, refer to subject listings in the index.

Although this edition reflects the results of experience mainly in the United States, it also reports the experiences of people in other countries. Studies similar to those that preceded the earlier editions were continued, or intensified, for this third edition, especially in the areas of the classification of soils and the interpretation of soil surveys. In addition, many soil scientists in the United States and abroad tested the definitions, concepts, and techniques before they were printed in this current edition.

The chapters of the Manual are arranged in the approximate chronological order in which the work required for a published soil survey is done. As background for the chapters that follow, the first chapter defines the concepts of soils and the nature of soils as geographic bodies, and the second describes the nature and uses of soil surveys, the kinds of soil surveys, and the map units.

The succeeding chapters describe procedures and conventions of soil surveys from the start of a survey to its publication. Chapter 3 deals with the attributes of bodies of soil that are mapped and the details of their internal properties. The fourth chapter tells how to prepare a mapping legend and the descriptive legend, which contains the technical instructions for mapping soils and related activities. Only after these facts are known can the units to be mapped be defined and identified consistently. The fourth chapter also describes the supplies, equipment, and mapping bases required for conducting a soil survey. Data are accumulated during all of these activities. Chapter 5 describes the ways in which data are recorded, stored, and retrieved.

After the mapping is completed and related data about the soils are gathered, the information must be provided to those who use it in forms they can understand. Chapter 6, therefore, discusses interpretations of soil surveys. The final product is the published soil survey. Chapter 7

describes the publication of the soil survey map, the accompanying text, and other publications based on the findings of soil surveys.

All serious users of the Manual will benefit from complementary reading in the classification and genesis of soils, geology, climatology, engineering, forestry, hydrology, and urban and country planning.

Many dedicated SCS staffers have made significant contributions to the information published in this edition of *Soil Survey Manual*. Work on the *Manual* was started by Martin G. Cline, Professor Emeritus, Cornell University, Ithaca, New York. It was completed at the National Soil Survey Center, Lincoln, Nebraska, by Richard W. Fenwick, retired soil scientist, and Robert B. Grossman, research soil scientist. Robert J. Ahrens and Robert J. Engel, soil scientists at the National Soil Survey Center, updated this edition of the *Manual* in 1993.

CHAPTER 1

Soil and Soil Survey

A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of classification, plots the boundaries of the soils on a map, and makes predictions about the behavior of soils. The different uses of the soils and how the response of management affects them are considered. The information collected in a soil survey helps in the development of land-use plans and evaluates and predicts the effects of land use on the environment.

Soil surveys were first authorized in the United States in 1896. Although extensive writings on husbandry by L.J.M. Columella were published in the first century A.D., practical experience was the teacher of most farmers until the advent of agricultural chemistry in the nineteenth century. By the end of the nineteenth century the knowledge about soils that had been gained from farming, agricultural chemistry, biology, and geology grew into a unified concept of the soil itself.

Early Concepts

The first scholar to study soils in the United States was Edmund Ruffin of Virginia. He worked diligently to find the secret of liming and discovered what we now call exchangeable calcium. After writing a brief essay in the *American Farmer* in 1822, he published the first edition of *An Essay on Calcareous Manures* in 1832. Much of what Ruffin had learned about soils had to be rediscovered because his writings circulated only in the South.

E.W. Hilgard was one of the first true pedologists in the United States, but he never received the credit that his accomplishments deserved during his lifetime. The early concepts of soil were based on ideas developed by a German chemist, Justus von Liebig, and modified and refined by agricultural scientists who worked on samples of soil in laboratories, greenhouses, and on small field plots. The soils were rarely examined below the depth of normal tillage. These chemists held the "balance-sheet" theory of plant nutrition. Soil was considered a more or less static storage bin for plant nutrients—the soils could be used and

replaced. This concept still has value when applied within the framework of modern soil science, although a useful understanding of soils goes beyond the removal of nutrients from soil by harvested crops and their return in manure, lime, and fertilizer.

The early geologists generally accepted the balance-sheet theory of soil fertility and applied it within the framework of their own discipline. They described soil as disintegrated rock of various sorts—granite, sandstone, glacial till, and the like. They went further, however, and described how the weathering processes modified this material and how geologic processes shaped it into landforms such as glacial moraines, alluvial plains, loess plains, and marine terraces. N.S. Shaler's monograph on the origin and nature of soils summarized the late 19th century geological concept of soils (Shaler, 1891). In 1906, other details were added by G.P. Merrill.

Near the end of the nineteenth century, Professor Milton Whitney inaugurated the National Soil Survey Program (Jenny, 1961). Professor Whitney and his coworkers in the newly organized soil research unit of the U.S. Department of Agriculture became impressed by the great variations among natural soils—persistent variations that were in no way related to the effects of agricultural use. Whitney and his coworkers emphasized soil texture and the capacity of the soil to furnish plants with moisture as well as nutrients. Professor F.H. King of the University of Wisconsin was also reporting the importance of the physical properties of soils about this time (King, 1910).

Early soil surveys were made to help farmers locate soils responsive to different management practices and to help them decide what crops and management practices were most suitable for the particular kinds of soil on their farms. Many of the early workers were geologists because only geologists were skilled in the necessary field methods and in scientific correlation appropriate to the study of soils. They conceived soils as mainly the weathering products of geologic formations, defined by landform and lithologic composition. Most of the soil surveys published before 1910 were strongly influenced by these concepts. Those published from 1910 to 1920 gradually added greater refinements and recognized more soil features but retained fundamentally geological concepts.

Early field workers soon learned that many important soil properties were not necessarily related to either landform or kind of rock. They noted that soils with poor natural drainage had different properties from soils with good natural drainage and that many sloping soils were unlike level ones. Topography was clearly related to soil profile differences. As early as 1902, soil structure was described in the soil survey of Dubuque County, Iowa. The 1904 soil survey of Tama County, Iowa,

reported that, on similar parent material, soils that had formed under forest contrasted markedly with soils that had formed under grass.

The balance-sheet theory of plant nutrition dominated the laboratory and the geological concept dominated field work. Both approaches were taught in many classrooms until the late 1920's. Although broader and more generally useful concepts of soil were being developed by some soil scientists, especially E.W. Hilgard (Hilgard, 1860) and G.N. Coffey (Coffey, 1912) in the United States and soil scientists in Russia, the necessary data for formulating these broader concepts came from the field work of the soil survey during the first decade of its operations in the United States. After the work of Hilgard, the longest step toward a more satisfactory concept of soil was made by G.N. Coffey, who determined the ideal classification to be a hierarchical system that was based on the unique characteristics of soil as "a natural body having a definite genesis and distinct nature of its own and occupying an independent position in the formations constituting the surface of the earth" (Cline, 1977).

Beginning in 1870, the Russian school of soil science under the leadership of V.V. Dokuchaiev and N.M. Sibertsev was developing a new concept of soil. The Russian workers conceived of soils as independent natural bodies, each with unique properties resulting from a unique combination of climate, living matter, parent material, relief, and time (Gedroiz, 1927). They hypothesized that properties of each soil reflected the combined effects of the particular set of genetic factors responsible for the soil's formation. Hans Jenny later emphasized the functionally relatedness of soil properties and soil formation. The results of this work became generally available to Americans through the publication in 1914 of K.D. Glinka's textbook in German and especially through its translation into English by C.F. Marbut in 1927 (Glinka, 1927).

The Russian concepts were revolutionary. Properties of soils no longer were based wholly on inferences from the nature of the rocks or from climate or other environmental factors, considered singly or collectively; rather, by going directly to the soil itself, the integrated expression of all these factors could be seen in the morphology of the soils. This concept required that *all properties* of soils be considered collectively in terms of a completely integrated natural body. In short, it made possible a *science* of soil.

The early enthusiasm for the new concept and for the rising new discipline of soil science led some to suggest the study of soil could proceed without regard to the older concepts derived from geology and agricultural chemistry. Certainly the reverse is true. Besides laying the foundation for a soil science with its own principles, the new concept makes the other sciences even more useful. Soil morphology provides a

firm basis on which to group the results of observation, experiments, and practical experience and to develop integrated principles that predict the behavior of the soils.

Under the leadership of Marbut, the Russian concept was broadened and adapted to conditions in the United States (Marbut, 1921). As mentioned before, this concept emphasized individual soil profiles to the subordination of external soil features and surface geology. By emphasizing soil profiles, however, soil scientists at first tended to overlook the natural variability of soils which can be substantial even within a small area. Overlooking the variability of soils seriously reduced the value of the maps which showed the location of the soils. This weakness soon became evident in the United States, perhaps because of the emphasis here on making detailed soil maps for their practical, predictive value. Progress in transforming the profile concept into a more reliable predictive tool was rapid because a large body of important field data had already been accumulated. By 1925, a large amount of morphological and chemical work was being done on soils throughout the country. The data available by 1930 were summarized and interpreted in accordance with this concept, as viewed by Marbut in his work on the soils of the United States (Marbut, 1935).

Furthermore, early emphasis on genetic soil profiles was so great as to suggest that material lacking a genetic profile, such as recent alluvium, was not soil. A sharp distinction was drawn between rock weathering and soil formation. Although a distinction between these sets of processes is useful for some purposes, rock and mineral weathering and soil formation are commonly indistinguishable.

The concept of soil was gradually broadened and extended during the years following 1930, essentially through consolidation and balance. The major emphasis had been on the soil profile. After 1930, morphological studies were extended from single pits to long trenches or a series of pits in an area of a soil. The morphology of a soil came to be described by ranges of properties deviating from a central concept instead of by a single "typical" profile. The development of techniques for mineralogical studies of clays also emphasized the need for laboratory studies.

Marbut emphasized strongly that classification of soils should be based on morphology instead of on theories of soil genesis, because theories are both ephemeral and dynamic. He perhaps overemphasized this point to offset other workers who assumed that soils had certain characteristics without examining the soils. Marbut tried to make clear that examination of the soils themselves was essential in developing a system of Soil Classification and in making usable soil maps. In spite of this, Marbut's work reveals his personal understanding of the contributions

of geology to soil science. His soil classification of 1935 depends heavily on the concept of a "normal soil," the product of equilibrium on a landscape where downward erosion keeps pace with soil formation.

Clarification and broadening of the concept of a soil science also grew out of the increasing emphasis on detailed soil mapping. Concepts changed with increased emphasis on predicting crop yields for each kind of soil shown on the maps. Many of the older descriptions of soils had not been quantitative enough and the units of classification had been too heterogeneous for making yield and management predictions needed for planning the management of individual farms or fields.

During the 1930's, soil formation was explained in terms of loosely conceived processes, such as "podzolization," "laterization," and "calcification." These were presumed to be unique processes responsible for the observed common properties of the soils of a region (Jenny, 1946).

In 1941 Hans Jenny's *Factors of Soil Formation*, a system of quantitative pedology, concisely summarized and illustrated many of the basic principles of modern soil science to that date (Jenny, 1941). Since 1940, time has assumed much greater significance among the factors of soil formation, and geomorphological studies have become important in determining the time that soil material at any place has been subjected to soil-forming processes. Meanwhile, advances in soil chemistry, soil physics, soil mineralogy, and soil biology, as well as in the basic sciences that underlie them, have added new tools and new dimensions to the study of soil formation. As a consequence, the formation of soil has come to be treated as the aggregate of many interrelated physical, chemical, and biological processes. These processes are subject to quantitative study in soil physics, soil chemistry, soil mineralogy, and soil biology. The focus of attention also has shifted from the study of gross attributes of the whole soil to the co-varying detail of individual parts, including grain-to-grain relationships.

In both the classification of Marbut and the 1938 classification developed by the U.S. Department of Agriculture, the classes were described mainly in qualitative terms. Classes were not defined in quantitative terms that would permit consistent application of the system by different scientists. Neither system definitely linked the classes of its higher categories, largely influenced by genetic concepts initiated by the Russian soil scientists, to the soil series and their subdivisions that were used in soil mapping in the United States. Both systems reflected the concepts and theories of soil genesis of the time, which were themselves predominantly qualitative in character. Modification of the 1938 system in 1949 corrected some of its deficiencies but also illustrated the need for a reappraisal of concepts and principles. More than 15 years of work

under the leadership of Guy Smith culminated in a new soil classification system. This became the official classification system of the U.S. National Cooperative Soil Survey in 1965 and was published in 1975 as *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys* (Soil Survey Staff, 1975).

Categories and classes of the new taxonomy are direct consequences of new and revised concepts and theories. The system of soil classification discussed in *Soil Taxonomy* is dynamic and will change as new knowledge is obtained. Its most significant contribution comes from defining class limits quantitatively. The theories on which the system is based are tested every time the taxonomy is applied. For soil survey, the application of quantitatively defined classes to bodies of soil produces quantitatively defined mapping units. This permits the soil maps to be interpreted with more precision than was formerly achieved. Furthermore, this soil-classification system simplifies and accelerates the process of soil correlation.

In addition to the new soil classification system, several other techniques have contributed to the increased precision of soil survey. The use of aerial photographs as mapping bases became almost universal in detailed soil mapping during the late 1930's and early 1940's. Using aerial photographs has greatly increased the precision with which soil boundaries can be delineated on maps. At the same time, the scale of published maps was increased from about 1:63,360 to 1:24,000 to 1:15,840. The smallest area that can be delineated legibly at a scale of 1:63,360 is about 15.8 ha; areas of 1 ha can be delineated legibly at a scale of 1:15,840.

Another factor has had an immense impact on soil survey, especially during the 1960's. Before 1950, the primary applications of soil surveys were farming, ranching, and forestry. Applications for highway planning were recognized in some States as early as the late 1920's, and soil interpretations were placed in field manuals for highway engineers of some States during the 1930's and 1940's. Nevertheless, the changes in soil surveys during this period were mainly responses to the needs of farming, ranching, and forestry. During the 1950's and 1960's nonfarm uses of the soil increased rapidly. This created a great need for information about the effects of soils on those nonfarm uses.

Beginning about 1950, cooperative research with the Bureau of Public Roads and State highway departments established a firm basis for applying soil surveys to road construction. Soil scientists, engineers, and others have worked together to develop interpretations of soils for roads and other nonfarm uses. These interpretations, which have become standard parts of published soil surveys, require different information about soils. Some soil properties that are not important for

growth of plants are very important in evaluating soils for building sites, sewage disposal systems, highways, pipelines, and recreation. Many of these uses of soil require very large capital investments per unit area; errors can be extremely costly. Consequently, the location of soil boundaries, the identification of the areas delineated, and the quantitative definition of map units have assumed great importance.

Modern Concept of Soil

Soil is "the collection of natural bodies in the earth's [sic] surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors. Its upper limit is air or shallow water. At its margins it grades to deep water or to barren areas of rock or ice. Its lower limit to the not-soil beneath is perhaps the most difficult to define. Soil includes the horizons near the surface that differ from the underlying rock material as a result of interactions, through time, of climate, living organisms, parent materials, and relief. In the few places where it contains thin cemented horizons that are impermeable to roots, soil is as deep as the deepest horizon. More commonly soil grades at its lower margin to hard rock or to earthy materials virtually devoid of roots, animals, or marks of other biologic activity. The lower limit of soil, therefore, is normally the lower limit of biologic activity, which generally coincides with the common rooting depth of native perennial plants" (Soil Survey Staff, 1975).

The "natural bodies" of this definition include all genetically related parts of the soil. A given part, such as a cemented layer, may not contain living matter or be capable of supporting plants. It is, however, still a part of the soil if it is genetically related to the other parts and if the body as a unit contains living matter and is capable of supporting plants.

The definition includes as soil all natural bodies that contain living matter and are capable of supporting plants even though they do not have genetically differentiated parts. A fresh deposit of alluvium or earthy constructed fill is soil if it can support plants.

To be soil, a natural body must contain living matter. This excludes former soils now buried below the effects of organisms. This is not to say that buried soils may not be characterized by reference to taxonomic classes. It merely means that they are not *now* members of the collection of natural bodies called soil; they are buried paleosols.

Not everything "capable of supporting plants out-of-doors" is soil. Bodies of water that support floating plants, such as algae, are not soil, but the sediment below shallow water is soil if it can support bottom-rooting plants such as cattails or reeds. The above-ground parts of plants

are also not soil, although they may support parasitic plants. Rock that mainly supports lichens on the surface or plants only in widely spaced cracks is also excluded.

The time transition from not-soil to soil can be illustrated by recent lava flows in warm regions under heavy and very frequent rainfall. Plants become established very quickly in such climates on the basaltic lava, even through there is very little earthy material. The plants are supported by the porous rock filled with water containing plant nutrients. Organic matter soon accumulates; but, before it does, the dominantly porous broken lava in which plant roots grow is soil.

More than 50 years ago, Marbut's definition of soil as the "outer layer" of the Earth's crust implied a concept of soil as a continuum (Marbut, 1935). The current definition refers to soil as a collection of natural bodies on the surface of the Earth, which divides Marbut's continuum into discrete, defined parts that can be treated as members of a population. The perspective of soil has changed from one in which the whole was emphasized and its parts were loosely defined to one in which the parts are sharply defined and the whole is an organized collection of these parts.

Factors that Control the Distribution of Soils

The properties of soil vary from place to place, but this variation is not random. Natural soil bodies are the result of climate and living organisms acting on parent material, with topography or local relief exerting a modifying influence and with time required for soil-forming processes to act. For the most part, soils are the same wherever all elements of the five factors are the same. Under similar environments in different places, soils are similar. This regularity permits prediction of the location of many different kinds of soil.

When soils are studied in small areas, the effects of topography or local relief, parent material, and time on soil becomes apparent. In the humid region, for example, wet soils and the properties associated with wetness are common in low-lying places; better drained soils form in most instances in higher lying areas. The correct conclusion is that *topography* or *relief* is important. In arid regions, the differences associated with relief may be salinity or sodicity, but the conclusion is the same. In a local environment, different soils are associated with contrasting parent materials, such as residuum from shale and from sandstone, and the correct conclusion is that *parent material* is important. Soils on a flood plain differ from soils on higher and older terraces where there is no longer deposition of parent material on the surface. The correct conclusion is that *time* is impor-

tant. The influence of topography, parent material, and time on the formation of soil is observed repeatedly while studying the soils of an area.

With the notable exception of the contrasting patterns of vegetation in transition zones, local differences in vegetation are closely associated with differences in relief, parent material, or time. The effects of microclimate on vegetation may be reflected in the soil, but such effects are likely associated with differences in local relief.

Regional climate and vegetation influence the soil as well as topography or relief, parent material, and time. In spite of local differences, most of the soils in an area typically have some properties in common. The low-base status of many soils in humid or naturally acid rock or sediment regions stands in marked contrast to the typical, high-base status in arid or calcareous sandstone or limestone regions. To one who has studied soils only on old landscapes of humid regions, however, low base status is so commonplace that little significance is attached to it.

Regional patterns of climate, vegetation, and parent material can be used to predict the kinds of soil in large areas. The local patterns of topography or relief, parent material, and time, and their relationships to vegetation and microclimate, can be used to predict the kinds of soil in small areas. Soil surveyors learn to use local features, especially topography and associated vegetation, as marks of unique combinations of all five factors. These features are used to predict boundaries of different kinds of soil and to predict some of the properties of the soil within those boundaries.

Soil-Landscape Relationships

Geographic order suggests natural relationships. Running water, with weathering and gravitation, commonly sculptures landforms within a landscape. Over the ages, earthy material has been removed from some landforms and deposited on others. Landforms are interrelated. An entire area has unity through the interrelationships of its landforms.

Each distinguishable landform may have one kind of soil or several. Climate, including its change with time, commonly will have been about the same throughout the extent of a minor landform. The kinds of vegetation associated with climate also likely will have been fairly uniform. Relief varies within some limits that are characteristic of the landform. The time that the material has been subjected to soil formation has probably been about the same throughout the landform. The surface of the landform may extend through one kind of parent material and into another. Of course, position on the landform may have influenced soil-water relationships, microclimate, and vegetation.

Just as different kinds of soil are commonly associated in a landscape, several landscapes are commonly associated in still larger areas. These areas cover thousands or tens of thousands of square kilometers. Many can be identified on photographs taken from satellites. From this vantage point, broad geomorphic units—the East Gulf Coastal Plain, the Allegheny Plateau, the Laramie Basin, and the Great Valley of California—are apparent. These broad units usually have some unity of landscape, which is characterized by such terms as "plain," "plateau," and "mountain." These physiographic units are composed of many kinds of soil.

The main relief features of a physiographic unit are usually the joint products of deep-seated forces and a complex set of surface processes that have acted over long spans of time. Within a physiographic unit, groups of minor landforms are shaped principally by climate-controlled processes. The climate and biological factors, however, vary much less within a geomorphic unit than across a continent.

Still broader than the geomorphic units are great morphogenetic regions having distinctive climates. For example, one classification recognizes glacial, periglacial, arid, semiarid-subhumid, humid-temperate, and humid-tropical climatic regions associated with distinctive sets of geomorphic processes. Other major regions characterized by seasonal climatic variation are also recognized. These geomorphic-climatic regions are related to soil moisture and soil temperature regimes.

Thus, the great climatic regions are divided into major geomorphic units. Landforms and associated soil landscapes are small parts of these units and are commonly of relatively recent origin.

The landforms of concern in soil mapping may include constructional units, such as glacial moraines, and elements of local sequences of graded erosional and constructional land surfaces. These bear the imprint of local, base-level controls under climate-induced processes. Most surfaces that have formed within the last 10,000 years have been subject to climatic and base-level controls similar to those of the present. Older surfaces may retain the imprint of climatic conditions and related vegetation of the distant past. Most landforms of the present started to form during the Quaternary Period; some started in late Tertiary time. In many places conditions of the past differed significantly from those of the present. Understanding climatic changes locally and worldwide far into the past contributes to understanding the attributes of landforms in the present.

Geomorphic processes are important in mapping soils. Soil scientists need a working knowledge of local geomorphic relationships in areas where they map and should understand the interpretations of landforms and land surfaces made by geomorphologists. The intricate

interrelationships of soil and landscape are best studied by a collaboration between soil scientists and geomorphologists.

Development of the Soil Survey

Soil surveys were authorized in the United States by the U.S. Department of Agriculture Appropriations Act for fiscal year 1896, which provided funds for an investigation "of the relation of soils to climate and organic life" and "of the texture and composition of soils in field and laboratory."

In 1899 the U.S. Department of Agriculture completed field investigations and soil mapping of portions of Utah, Colorado, New Mexico, and Connecticut. Reports of these soil surveys and similar works were published by legislative directive. At the same time, the State of Maryland, using similar procedures and State funds, completed a soil survey of Cecil County. Since then many soil surveys have been initiated, completed, and published cooperatively by the Department of Agriculture, State agencies, and other Federal agencies. The total effort is the National Cooperative Soil Survey (NCSS).

The early soil surveys investigated the use of soils for farming, ranching, and forestry. As experience was acquired in the use of soil surveys, predictions were made about other uses, such as highways, airfields, and residential and industrial developments. As the making and the use of soil surveys expanded, the knowledge about soils—about their nature, occurrence, and behavior for defined uses and management—also increased. The Highway Department of Michigan was applying soil survey experience to assist in planning highway construction in the late 1920's. At about the same time soil surveys in North Dakota were used in tax assessment.

Soil surveys published between 1920 and 1930 reveal a marked transition from earlier concepts to give emphasis to soil profiles and soils as independent bodies. The maps retained significant geologic boundaries as soil maps do today. Many of the surveys of that period provide excellent general maps for evaluating engineering properties of geologic material. In addition, maps and texts of the period show more recognition of other soil properties significant to farming and forestry than do earlier surveys and have value for broad generalizations about farming practices in large areas.

The use of aerial photographs for soil mapping, which began during the late 1920's and early 1930's, greatly increased the precision of plotting soil boundaries. To meet the needs for planning the management of individual fields and farms, greater precision of interpretation

was required. The changing objectives of soil surveys initiated changes in methods and techniques that made surveys more useful and forced reconsideration of the concept of soil itself.

Beginning in the 1930's, the Soil Conservation Service (SCS) emphasized the control of soil erosion as it used soil surveys for the resource conservation planning of farms and ranches. In the 1950's, extensive use was made of soil survey information in urban land development in Fairfax County, Virginia, and in the subdivision design of suburban areas of Chicago, Illinois. Soil surveys were an important base for resource information in regional land-use planning in southeastern Wisconsin. Rural land zoning has also relied on soil surveys.

Soil surveys necessarily involve thousands of different kinds of soils—as many as there are significantly different combinations of genetic factors. The history of a soil and evidence of its potential for use are contained in the properties soil scientists are able to identify through observation and research in the field and laboratory. These properties determine the limitations, suitability, and potential for rural and urban land use of soils. Soil surveys are particularly valuable because they identify specific soil properties and help soil scientists make broad generalizations significant to farming and forestry practices.

The program of the NCSS can be divided into soil mapping, description of the mapping concepts, and the prediction of the behavior of these mapping concepts for various uses. Soil behavior prediction relies on the evaluated and named soil properties to interpret the concept of map units.

Soil Survey and the Soil Map

The different kinds of soil used to name *soil map units* have sets of interrelated properties that are characteristic of soil as a natural body. This definition is intended to exclude maps showing the distribution of a single soil property such as texture, slope, or depth, alone or in limited combinations; maps that show the distribution of soil qualities such as productivity or erodibility; and maps of soil-forming factors, such as climate, topography, vegetation, or geologic material. A soil map delineates areas occupied by different kinds of soil, each of which has a unique set of interrelated properties characteristic of the material from which it formed, its environment, and its history. The soils mapped by the NCSS are identified by names that serve as references to a national system of soil taxonomy.

The geographic distribution of many individual soil properties or soil qualities can be extracted from soil maps and shown on separate

maps for special purposes, such as showing predicted soil behavior for a particular use. The number of such interpretative maps that can be derived from a soil map is large, and each such map would differ from the others according to its purpose. A map made for one specific interpretation can rarely serve a different purpose.

Maps to show one or more soil properties can be made directly from field observations without making a basic soil map. Such maps serve their specific purposes but have few other applications. Predictions of soil behavior can also be mapped directly; however, most such interpretations need to be changed with changes in land use and in the cultural and economic environment. A map showing the productivity of crops on soils that are wet and undrained, for example, has little value after drainage systems have been installed. If the basic soil map is made accurately, interpretative maps can be revised as needed without doing additional fieldwork. In planning soil surveys, this point needs to be emphasized. Occasionally, "short-cut" inventories are made for some narrow objective, perhaps at a cost lower than that of a soil survey. Such maps quickly become obsolete. They cannot be revised without fieldwork because vital data are missing, facts are mixed with interpretations, or boundaries between significantly different soil units have been omitted.

The basic objective of soil surveys is the same for all kinds of land, although the number of mapping units, their composition, and the detail of mapping vary with the complexity of the soil patterns and the specific needs of the users. Thus a soil survey is matched to the soils and the soil-related problems of the area. Soil surveys increase our general knowledge about soils and serve practical purposes. They satisfy a need for soils information about specific geographic areas for State, county, and community land-use plans. These plans include resource conservation plans for farms and ranches, development of reclamation projects, forest management, engineering projects, as well as other purposes.

The storage and retrieval of soil survey data are possible through the use of Automatic Data Processing (ADP). ADP helps develop important interpretations and policy decisions for both the present and the future.

CHAPTER 2 Soil Systematics

The factors of soil formation are discussed in chapter 1. Climatic and biological factors generally produce broad geographic patterns. These have given rise to a zonal concept and definition of soil distribution. Parent materials contribute to soil variations within climatic and vegetative zones. Local topographic patterns add further complexity, affecting both the time of exposure to processes of soil formation and the kinds of processes. The complex interactions among these factors occur in repetitive patterns which lead to the formation of repetitive combinations. These are the basis for defining, identifying, and mapping soils.

The repetitive patterns imprinted in soils by the soil-forming factors can be observed at scales ranging from continental to microscopic. The patterns are the basis for soil identification and mapping at vastly different scales. A system of terminology, definitions, and operations can be ascribed to the various scales. Hierarchical systems of classes and subclasses can be set up to produce groupings at the different scales.

The National Cooperative Soil Survey of the United States has systems of descriptive terminology, class definitions, hierarchical soil groupings, and operations that are applicable to various scales and appropriate to a wide variety of uses. Development of such flexibility has, in turn, required a fairly complex system in which it is important to understand a number of philosophical, conceptual, and operational relationships. Foremost among these are the relationships between mapping units and taxonomic units, site data and mapping unit data, conceptual models and the real entities in the landscape.

Map units are designed to carry important information for the more common uses of soils in the survey area such as small grain, rural living, and small community development. The map units must also be easily recognizable and mappable at scales compatible with the available base maps, the time allocated to collecting the data, and the skills of the surveyors.

In the United States, soil surveys vary in scale and in intensity of observations. The components of map units are designated by taxa in *Soil Taxonomy* (Soil Survey Staff, 1975) and miscellaneous areas if they are present. Soil taxa are modified with phases, such as slope and stoni-

ness to convey more specific information. The phase often is a portion of the range of properties exhibited by the taxon. For example, a certain soil series may have slopes from 3 to more than 60 percent, but map units are shown with narrower ranges—such as 3 to 8, 8 to 15, 15 to 25—in order to provide information that is useful in managing the soils in the area.

Kinds of soils are known best by the characteristics embodied in small samples. Field descriptions of soil include horizon designation; depth and thickness; color; moist and dry; features of ped surfaces and interiors; texture; structure; consistence at several water states; and special features such as roots, pores, nodules, salts, rock fragments, pH, and boundary conditions. Site characteristics of the soil and its immediate surrounding are usually described. Chemical and physical data are obtained from horizon samples analyzed in a laboratory. Special features of microbial entities and activities are not routinely determined but may be carried out for research or special purposes.

All samples and all models of soils have a purpose in the soil survey program. Small samples from peds and profiles help us describe the properties of points and how they are organized. This mainly gives us a perspective of the results of soil genesis. We only know what is present by the techniques of measurement that are used, although we may speculate about what has been removed, changed, added, or translocated. Profile features are combined into models of soil formation and the processes and events of geomorphology that have influenced and helped shape the hypothesized features. These mental processes of model building permit us to shift readily from considering an ion in solution to the arrangement of horizons in profiles and their stratigraphic relationships across landscapes.

Purposive sampling of soil map units depends on whether the answers or relationships we desire are related in a meaningful way with the features of the soil map units. The actual clues are not necessarily soil properties at all but are features of identification that we associate with the unseen soil models. Mapping in most surveys involves delineating segments of the landscape, cutting out geographic areas, and putting the boundaries on base maps. Tonal shades and patterns on aerial photographs are used to indicate possible changes of vegetation, drainage conditions, materials, and so forth. The patterns of the gray tones are used to delineate areas on maps. As we look at the existing vegetation, we see differences of tones and composition of the species makeup, and we verify or modify the boundary locations of the units accordingly. Configurations of the visible surface of the land, stones, and other features are used as evidence of changes important enough to be recognized as separate areas. Finally, the soils are examined at a few locations

to verify the models being used in the mapping process.

Soil surveys are conducted so that all the clues, features, and pieces of evidence that support the delineations that are called soil map units are in fact surrogates for the models that have been established. The measure of models of landscape evolution and soil formation relative to observable landscape areas is provided by the constant testing that goes on in the soil survey. The outdoors is a laboratory in which variability is subject to some level of systematic portrayal. Thus the small items that are used to assist in locating, verifying, modifying, and developing soil models are similar to the criteria used to identify the basis of differentiation in the classification of soils.

Predictions of properties that exist in soil map units and the predictions made about the qualities and suitabilities and responses of areas of land are all based on the relationships that exist between the desired or expected result and the actuality that is represented by the models used in mapping.

Many schemes have been proposed and tested for determining the composition of map units. The same can be said for the distribution of properties that exist, or are thought to exist, in areas of the landscape that can be delineated consistently on base maps. It is fairly well accepted that certain features of soils and of landscapes are not in accord with existing models of distributions in systematic and predictable ways. The frequency of random events can readily be predicted and tested; however, the location of the occurrences associated with events is, and likely will remain, a probabilistic phenomenon. Such aberrant features are what gives rise to most of the inclusions in map units because their occurrence cannot be predicted and mapped with models even at larger scales. It is the nonsystematic features that make all models approximations of what actually takes place. The composition of map units can never be known. It can only be approximated from samples of them.

It is common to employ transects to estimate the composition of map units. The first aspect of composition is to identify the taxonomic components because they are the things that we have learned to identify and recognize. These can be translated or interpreted as responses or properties or whatever has an acceptable relationship. If results are not satisfactory or favorable, it is because the models are being used beyond their capability. As long as one is aware of the probability of accuracy or known variability, then soil survey information can have relevant use.

Transecting carries with it some important assumptions when it is used as a means of purposive sampling for map unit composition. A major assumption is that the points observed along a line will be representative of areas on the land that are shown as map units. This line varies in utility with different landscapes and models developed for soil surveys.

Transects crossing landscape units must cross all parts of the landscape, rather than line up with known patterns of variability as this would unduly bias the results. For example, transects that follow small steam valleys overweigh the alluvial-colluvial material relative to what occurs on the hillslopes and uplands. The differences between accuracy of line and point transects for grid points or sample plots is not the same for all landscapes and is better determined by some preliminary checking. Point transects have proven to be satisfactory for most surveys in the United States. Observations made at points along a transect are usually identified as belonging to a class... often a particular taxon, but they could be a combination of properties such as depth, a thickness, a color, or a structure. Because the assumption that point-to-area relationships are satisfactory, the number of observations in the various classes are handled as samples, and statistical inferences are made about the mean values and the ranges that are thought to exist.

Pedon and Polypedon

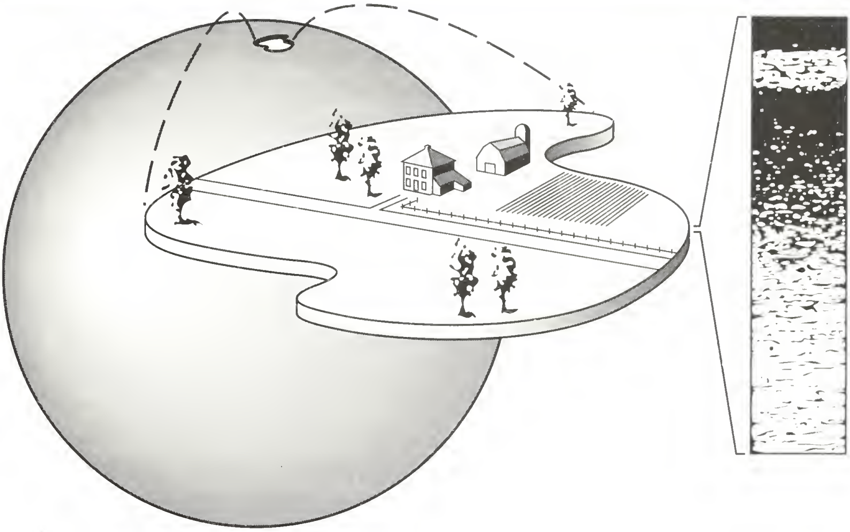
In soil surveys the individual parts that make up the soil continuum are classified. The classes are defined to include bodies of soil of significant kinds and sizes. The classes are concepts, not real soils, but they are related to their representatives in nature—the pedon and the polypedon.

Pedon.—The pedon is presented in *Soil Taxonomy* (Soil Survey Staff, 1975) as a unit of sampling within a soil. The limits on the area of a pedon establish rules for deciding whether to consider one or two or more kinds of soil within a small-scale pattern of local lateral variability. A pedon is regarded as the smallest body of one kind of soil large enough to represent the nature and arrangement of horizons and variability in the other properties that are preserved in samples.

A pedon extends down to the lower limit of a soil. It extends through all genetic horizons and, if the genetic horizons are thin, into the upper part of the underlying material. The pedon includes the rooting zone of most native perennial plants. For purposes of most soil surveys, a practical lower limit of the pedon is bedrock or a depth of about 2 m, whichever is shallower. A depth of 2 m provides a good sample of major soil horizons, even in thick soil. It includes much of the volume of soil penetrated by plant roots, and it permits reliable observations of soil properties.

The surface of a pedon is roughly polygonal and ranges from 1 m^2 to 10 m^2 in area, depending on the nature of the variability in the soil. Where the cycle of variations is less than 2 m and all horizons are continuous and nearly uniform in thickness, the pedon has an area of approximately 1 m^2. Where horizons or other properties are intermittent or

FIGURE 2-1



A schematic diagram of a polypedon as a unit soil body on the Earth's surface, illustrating (a) its characteristic landscape and (b) its unique set of internal properties. Its margins represent the geographic limits of a set of soil properties defined for a soil series (courtesy of Walter M. Simonson).

cyclic over an interval of 2 to 7 m, the pedon includes one-half of the cycle (1 to 3 ½ m). If horizons are cyclic over an interval greater than 7 m, each cycle is considered to contain more than one soil. The range in size, 1 to 10 m^2, permits consistent classification by different observers where important horizons are cyclic or repeatedly interrupted over short distances.

Polypedon.—The pedon is considered too small to exhibit more extensive features, such as slope and surface stoniness. The polypedon is presented in *Soil Taxonomy* as a unit of classification, a soil body, homogeneous at the series level, and big enough to exhibit all the soil characteristics considered in the description and classification of soils (fig. 2-1).

In practice, the concept of polypedon has been largely ignored and many soil scientists consider a pedon or some undefined body of more or less similar soil represented by a pedon large enough to classify. Polypedons seldom, if ever, serve as the real thing we want to classify because of the extreme difficulty of finding the boundary of a polypedon on the ground and because of the self-contradictory and circular nature of the concept. Soil scientists have classified pedons, regardless of their

limited size, by deliberately or unconsciously transferring to the pedon any required extensive properties from the surrounding area of soil.

George Holmgren incorporated this pragmatic, flexible view of the pedon in his proposal of the point pedon which combines the fixed position of a pedon with consideration of whatever area is needed to identify and measure the properties under consideration (Holmgren, 1988). This concept, combined with criteria for the scale of lateral variability to be considered within one kind of soil, could establish the pedon as the basic unit of classification and eliminate the need for the polypedon; however, the term "polypedon" will be used in this manual.

Polypedons link the real bodies of soil in nature to the mental concepts of taxonomic classes.

Soil Series

The soil series category is the most homogeneous category in the taxonomy used in the United States. As a class, a series is a group of soils or polypedons that have horizons similar in arrangement and in differentiating characteristics. The soils of a series have a relatively narrow range in sets of properties.

Soil series are differentiated on all the differentia of the higher categories plus those additional and significant characteristics in the series control section. Some of the characteristics commonly used to differentiate series are the kind, thickness, and arrangement of horizons and their structure, color, texture, reaction, consistence, content of carbonates and other salts, content of humus, content of rock fragments, and mineralogical composition. A significant difference in any one of these can be the basis for recognizing a different series. Very rarely, however, do two soil series differ in just one of these characteristics. Most characteristics are related, and generally several change together.

New series, variants, and taxadjuncts

Some soils are outside the limits of any recognized soil series and have unique sets of properties. These are potential new series. When such a soil is first recognized, it is described and identified as a taxon of the lowest category in which it can be classified. A phase of that taxon can be used to identify a map unit. In some surveys, including virtually all detailed surveys, greater refinement of definition is needed. For these, the soil is proposed as a *new series,* but the new series remains tentative until its properties can be described in detail, its extent determined, and any conflicts with established series resolved. If the soil proves to be unique and significant in extent, it is established as a new series.

Before October 1988, a soil that had characteristics outside the limits of any defined series and was less than 800 hectares (2,000 acres) in extent was designated as a *variant*. Variants differed enough in one or more properties from the series for which they were named that major interpretations for comparable phases were different. They were named by adding the word "Variant" to the name of a closely related series, preferably one within the survey area. Variants were potential soil series, and the soil was established as a new series if a significant area of a variant was eventually recognized.

Taxadjuncts are polypedons that have properties outside the range of any recognized series and are outside higher category class limits by one or more differentiating characteristics of the series. The differences in properties are small so that major interpretations are not affected. A taxadjunct is given the name of an established series that is most similar in characteristics. It is an adjunct to, but not part of, the named series. It is treated as if it were a member of the named series, and its interpretations are similar to those for comparable phases of the series for which it is named. The difference from the established series is described. Example: A potential series is in a fine-silty family particle size class, marginal to fine-loamy; however, it differs from an established fine-loamy series in only particle size and no appropriate fine-silty series has been identified. The potential series is given the name of the established series, and a new series is not proposed.

Phases

If a property of a taxon has too wide a range for the interpretations needed or if some feature outside the soil itself is significant for use and management, these are bases for defining phases. Phases commonly include only part of the range of features exhibited by a taxon, but phases can be based on attributes such as frost hazard, character of the deeper substratum, or physiographic position that are not characteristics used to identify taxa but, nevertheless, affect use and management. If these vary from place to place within the survey area, phases can be defined to accommodate the differences.

A soil map unit that bears the name of a phase of a taxon consists dominantly of that phase of the taxon, but it also includes other soil components. The other components are included because of the limitations imposed by the scale of mapping and the number of points that can be examined. *When the limits of soil taxa are superimposed on the pattern of soil in nature, areas of taxonomic classes rarely, if ever, coincide precisely with mappable areas.* Some polypedons are too small to be drawn on the map and are included in delineations and named for another soil. The boundaries

between polypedons are not always so obvious that they can be plotted precisely on a map, so part of one polypedon is commonly included in the delineation of an adjacent polypedon. Some polypedons are so intimately intermingled that mappable areas are necessarily identified in terms of two or more taxa. Other polypedons are not easily distinguished from similar adjacent ones and are inadvertently or deliberately included in delineations named for other soils because apparent differences in use and management are small.

Classes of soil properties are not necessarily used directly as phases. Defined class limits of properties are designed for a convenient description of soil, and they can also be used to define phases of soil where appropriate. But they are not useful for all soils. Distinctions significant for one kind of soil are not significant for every other kind. Any single property is significant only through its interactions with other properties. The usefulness of each phase must be repeatedly tested and verified during a survey. Separate phases of a taxon must differ significantly in behavior. If no useful purpose is served by separating them in mapping, similar phases of different taxa may be combined, and the combination described. The interpretations prepared during the course of a survey provide evidence of similarities and differences among map units.

The justification for most phases rests on the behavior of the soils under use. At least one statement about soil behavior must be unique to each phase of a taxon, and the differences of soil properties must exceed normal errors of observation.

Miscellaneous Areas

Some land areas have little or no soil and thus support little or no vegetation without major reclamation. Rock outcrop is an example. Such areas are called miscellaneous areas. The names of the different kinds of miscellaneous areas (discussed later) are used in the same manner as the names of soil taxa to identify map units.

Map Units

A *map unit* is a collection of areas defined and named the same in terms of their soil components or miscellaneous areas or both. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. Each individual area on the map is a *delineation.*

Map units consist of one or more components. An individual component of a map unit represents the collection of polypedons or parts of polypedons that are members of the taxon or a kind of miscellaneous area. Parts of polypedons are common when phases are used to divide a

taxon. Classes of miscellaneous areas are treated the same as soil taxa in soil surveys. A taxonomic unit description describes the ranges in soil properties exhibited in the polypedon for the maps in a survey area that are referenced by that taxonomic unit. The limits of these ranges are set for the taxonomic class of which a taxonomic unit is a member, but generally the full range allowed by the taxonomic class is not exhibited in a small survey area (<200,000 ha).

A delineation of a map unit generally contains the dominant components in the map unit name, but it may not always contain a representative of each kind of inclusion. A dominant component is represented in a delineation by a part of a polypedon, a complete polypedon, or several polypedons. A part of a polypedon is represented when the phase criteria, such as a slope, requires that a polypedon be divided. A complete polypedon is present when there are no phase criteria that require the subdivision of the polypedon or the features exhibited by the individual polypedon do not cross the limits of the phase. Several polypedons of a component may be represented if the map unit consists of two or more dominant components and the pattern is such that at least one component is not continuous but occurs as an isolated body or polypedon. Similarly, each inclusion in a delineation is represented by a part of a polypedon, a complete polypedon, or several polypedons. Their extent, however, is small relative to the extent of the dominant component(s). Soil boundaries can seldom be shown with complete accuracy on soil maps, hence parts and pieces of adjacent polypedons are inadvertently included or excluded from delineations.

A few delineations of some map units may not contain any of the dominant components named in the map unit description, but contain very similar soils. In most survey areas there are a few soils that occur as mappable bodies, but they have very limited total extent. They are normally included with other map units, if, for all practical purposes, interpretations are the same.

The kinds of map units used in a survey depend primarily on the purposes of the survey and the pattern of the soils and miscellaneous areas in the landscape. The pattern in nature is fixed and it is not exactly the same in each delineation of a given map unit. In soil surveys these patterns must be recognized and map units designed to meet the major objectives of the survey. It must be remembered that soil interpretations are made for areas of land and the most useful map units are those that group similarities.

Designing Map Units

While studying the soil patterns in different landscapes, the soil scientist

must keep in mind how best to relate the patterns observed to appropriate map units. The kinds of map units, the level of soil taxa, and the phases needed to satisfy the survey objectives must be determined. This requires many judgements. Every map unit that is tentatively identified is evaluated by two tests: (1) Can it be mapped consistently? (2) Is it needed to meet the objectives of the survey?

Designing map units to indicate significant differences in behavior among soils is particularly important to meet the current objectives of a survey. Reflecting differences in genesis and morphology is also important, even if no immediate differences in interpretations are known. Differences in soil properties that do not affect current interpretations may be important in the future; however, having too many delineations seriously reduces the immediate usefulness of a soil map. A potential benefit must be weighed carefully against the costs incurred in making additional separations. One objective of every soil survey is to record knowledge about soils, but this does not mean that the soil map must show the location of every kind of soil in a survey area or that the publication must record all that has been learned about the soils.

Taxonomic classes provide the basic sets of soil properties with which soil map units are defined. They summarize an immense amount of research and experience related to the significance of soil properties and combinations of properties. They provide predefined sets of soil properties that have been tested for genetic relationships and for interpretative value. Taxa provide a firm base for recognizing the components of potential map units in an unfamiliar area. Using established taxa is much easier than independently sorting out sets of properties and determining significant class limits.

The objectives of a survey determine the kind of map units and the taxonomic level used to identify components of map units. For the more detailed surveys, decisions must be made about what criteria to use to recognize phases of soil series, how broadly or narrowly to define the phases, and whether similar phases of different series have such similar interpretations that they can be combined. For the less detailed surveys, decisions must be made about how the complexities of soil in large areas can be best identified for purposes of the survey, what combinations of soils characterize useful and mappable units, what taxonomic level should be used in naming map units, and which phases contribute to the usefulness of the map units.

The names of soil taxa, along with one or more modifying terms are used to identify the soils in map units. For example, the name "Tama silt loam, 2 to 5 percent slopes," indicates that soils of the Tama series (a Udoll) are dominant in that map unit. The names of taxa of higher cate-

gories are also used in map unit names, especially on small scale maps. "Udolls, rolling," for example, identifies a map unit consisting dominantly of soils of the Udoll suborder, which includes Tama and other series. The name of a taxon of the lowest category that accurately identifies the dominant soil is commonly used.

Within each survey, soil maps can be designed with component taxa of low or high categories that reflect narrowly or broadly defined ranges of soil properties. In addition, soil map units can be designed with different compositions of soil taxonomic units and mapping inclusions. This flexibility permits the design of map units that will be most useful for the purposes of a specific survey as well as for the attainment of as much uniformity in mapping as possible.

As methods of measuring soil properties are refined, as experience in the field increases, and as use and management requirements are intensified, progressively narrower ranges in soil properties can be recognized or established. Narrow ranges of properties are not established just because methods permit it. Unnecessary separations are time consuming to delineate consistently, and they make the survey difficult to use. Not separating two significantly different, mappable units, however, makes a survey less useful. The significance of each map unit in meeting the objectives of the survey must be constantly evaluated during the mapping process.

Improper use of phases to designate map units and misinterpretations of soil survey procedures can result in unreasonably detailed soil maps delineating unnecessary map units or ones in less detail than is needed to accomplish the objectives of the survey. Using pre-established classes of selected soil properties—surface texture, depth, slope, accelerated erosion, and stoniness—as phase criteria and then using all combinations of these in defining phases, creates problems. Meaningless map units cause an unnecessary expense.

Phase distinctions must be compatible with natural variability. To illustrate, a series may range in depth to bedrock from 1.5 m to more than 2 m. For some uses, a separation at 1.5 m would be significant. If within a survey area the soils of a series range in depth to bedrock from slightly less than 1.75 m to slightly more, designating two depth phases cannot be justified. The mapping is likely to be inconsistent and the difference of a few centimeters in depth is likely to be of minor significance. In this case it is far better to designate only one phase on the basis of depth to bedrock. The description of the map unit should, of course, give the depth range.

Another example: In some areas a slope of 8 percent is about the upper limit for cropping many soils without special practices for erosion

FIGURE 2-2

An area of a soil complex where plowing 12 inches deep turns up the dark-colored spots in the subsoil. Note the uniform color of the areas on the left that have not been "deep plowed."

control; yet, in some series a large part of the soil has slopes of less than 3 percent, most of the rest has slopes of 6 to 10 percent, and a small acreage has slopes of 3 to 6 percent. Dividing phases of such soils at 8 percent slope would produce a large number of delineations having a gradient a little below 8 percent and a large number having a gradient a little above 8 percent. The differences in interpretations of the phases thus defined would probably not be consistently significant. For these soils, slope phases could be set at 0 to 3 percent, 3 to 6 percent, and 6 to 10 percent; or, if there is little or no significance of the break at 3 percent, they could be set at 0 to 6 percent and 6 to 10 percent.

Phases must also be compatible with practical needs. In a hypothetical survey area that is relevant to farming, the polypedons of Alpha soils are similar in all properties except stoniness and slope. The areas range from nearly stone-free to very stony and from undulating to steep. The most important single distinction for farming is the distinction between areas that can be cultivated feasibly and areas that cannot. As many as three mappable classes of stoniness could be combined with four mappable classes of slope—a total of 12 potential phases. Four of these twelve phases might be used to distinguish combinations of degrees of slope and degrees of stoniness within the limits that permit cultivation. Using the remaining eight to subdivide the nonarable areas would confuse the user with unnecessary detail more than it would

help. Perhaps two, and probably no more than three, phases are adequate for all significant distinctions among nonarable areas if the survey area is to be used primarily for farming. A list of potentially useful phases is as follows:

A. Arable areas:

1. An undulating, nonstony phase
2. An undulating, moderately stony phase
3. A rolling, nonstony phase
4. A rolling, moderately stony phase

B. Nonarable areas:

1. An undulating and rolling, very stony phase
2. A hilly phase (ranging from nonstony to very stony)
3. A steep phase (ranging from nonstony to very stony)

If the soil map is to be used for planning operations related to forestry or other nonfarming activities, other distinctions may be needed.

The object of surveying soils is to gather relevant facts, record the facts on maps, and then interpret the facts. Field records and observations together with other relevant information must be coordinated in defining phases and map units that meet the objectives of a soil survey.

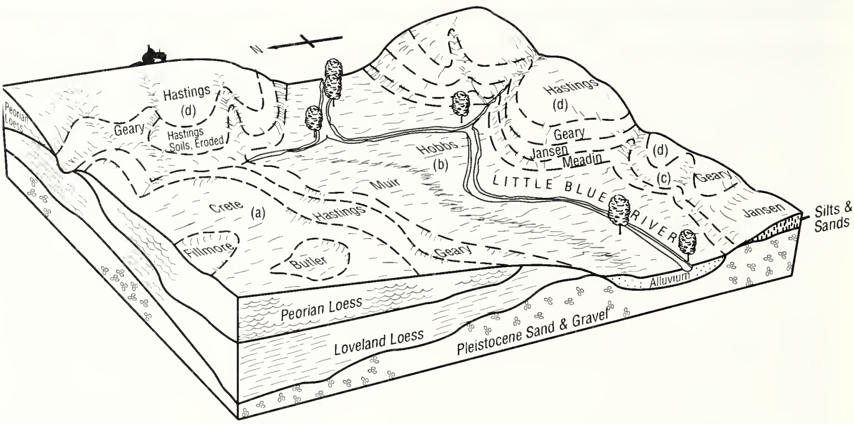
Kinds of Map Units

Soils differ in size and shape of their areas, in degree of contrast with adjacent soils, and in geographic relationships. Four kinds of map units are used in soil surveys to show the relationships: *consociations, complexes, associations,* and *undifferentiated groups.*

Consociations—In a consociation, delineated areas are dominated by a single soil taxon (or miscellaneous area) and similar soils. As a rule, at least one-half of the pedons in each delineation of a soil consociation are of the same soil components that provide the name for the map unit.[1] Most of the remainder of the delineation consists of soil components so similar to the named soil that major interpretations are not affected significantly. The total amount of dissimilar inclusions of other components in a map unit generally does not exceed about 15 percent if limiting and 25 percent if nonlimiting. A single component of dissimilar limiting

[1]Some soil consociations may be less than one-half the named soil if most of the remainder of the map unit consists of two or more soils that are similar to the named soil. The unit is named for the dominant soil.

FIGURE 2-3



Landscapes of Associations of Soil Series (Soil Survey Thayer Co., Nebraska).

inclusion generally does not exceed 10 percent if very contrasting. The amount of dissimilar inclusions in an individual delineation of a map unit can be greater than this if no useful purpose would be served by defining a new map unit. The soil in a consociation may be identified at any taxonomic level.

A consociation named for a kind of miscellaneous area is dominated by the kind of area for which it is named to the extent that inclusions do not significantly affect the use of the map unit. Generally, this means that less than about 15 percent of any delineation is soil or less than about 25 percent is other kinds of miscellaneous areas. Percentages may vary, depending on the kind of miscellaneous area and the kind, size, and pattern of the inclusions.

Complexes and associations—Complexes and associations consist of two or more dissimilar components occurring in a regularly repeating pattern. Only the following arbitrary rule related to mapping scale determines whether the name complex or association should be used. The major components of a complex cannot be mapped separately at a scale of about 1:24,000 (fig. 2-2). The major components of an association can be separated at a scale of about 1:24,000 (fig. 2-3). In either case, the major components are sufficiently different in morphology or behavior that the map unit cannot be called a consociation. In each delineation of either a complex or an association, each major component is normally present, though their proportions may vary appreciably from one delineation to another. The total amount of inclusions in a map unit that are dissimilar

to any of the major components does not exceed about 15 percent if limiting and 25 percent if nonlimiting, and a single kind of dissimilar limiting inclusion generally does not exceed 10 percent if very contrasting.

Undifferentiated groups—Undifferentiated groups consist of two or more taxa components that are not consistently associated geographically and, therefore, do not always occur together in the same map delineation. These taxa are included as the same named map unit because use and management are the same or very similar for common uses. Generally, they are included together because some common feature such as steepness, stoniness, or flooding determines use and management. If two or more very steep soils geographically separated are so similar in their potentials for use and management that defining two or more additional map units would serve no useful purpose, they may be placed in the same unit. Every delineation has at least one of the major components and some may have all of them. The same principles regarding proportion of inclusions apply to undifferentiated groups as to consociations.

Inclusions within map units

In all soil surveys, virtually every delineation of a map unit includes areas of soil components or miscellaneous areas that are not identified in the name of the map unit. Many areas of these components are too small to be delineated separately. The location of some components cannot be identified by practical field methods. Some mapping inclusions are deliberately placed in delineations identified as another map unit to avoid excessive detail of the map or the legend.

Inclusions reduce the homogeneity of map units and may affect interpretations. The objective is to define map units that will contain as few inclusions as practical of components that behave differently from the naming components. Also, map units must be so defined that they can be recognized and delineated consistently in the field.

The number of inclusions reflects the taxonomic purity of map units. The number and degree of contrast of inclusions with the reference taxa can be used to estimate the interpretative purity of map units. The actual amount of inclusions is estimated from observations made during the survey. Adjustments in mapping are made if appropriate.

In the definition of map units, judgement must be exercised about the effects of inclusions on management and about how much effort is justified to keep the amount of inclusions small. In exercising these judgements, visualizing two kinds of differences between components is useful. If differences are small, the components are compared as similar. If differences are large, the components are contrasted as dissimilar.

Similar components are alike or much alike in most properties and share limits of those diagnostic properties in which they differ. Differences are beyond the limits of the reference taxon or phase class, but they generally are within or slightly beyond normal errors of observation. Because only a few limits are shared or the range is small, interpretations for most common uses are alike or reasonably similar and the interpretative value of a map unit is not affected.

Dissimilar components on the other hand, differ appreciably in one or more properties, and the differences generally are great enough to affect major interpretations. Some dissimilar components are limiting, and others are nonlimiting relative to the interpretations being considered.

If an inclusion does not restrict the use of entire areas or impose limitations on the feasibility of management practices, its impact on predictions for the map unit is small. Inclusions of soil components that have less severe restrictions on use than the dominant soil of a map unit do not adversely affect predictions about the unit as a whole. They may even be beneficial. Such inclusions are nonlimiting and the interpretative purity of a map unit for most interpretations is not altered.

For example, the inclusion of many small areas having slopes of 4 to 8 percent in an area having slopes mainly of 15 to 25 percent has no adverse effect on use of the area for most purposes; however, if an inclusion has significantly lower potential for use than the dominant component in the map unit or affects the feasibility of meeting management needs, a small amount in a map can affect predictions greatly. These are the most critical inclusions because they decrease the interpretative purity of map units. Even a small area having slopes of 15 to 25 percent in a map unit dominated by slopes of 4 to 8 percent can seriously affect the use of the area for many purposes. Even small inclusions of Typic Epiaqualfs in areas of Aquic Hapludalfs, for an example, may control and limit the uses of the dominant soil.

Soils that cannot be used feasibly for the same purposes as the surrounding soils are especially critical. They are separately delineated if the map scale permits it and if showing them will improve the usefulness of the map for the major anticipated uses. Areas too small to delineate may be identified and located on the map by special symbols.

Naming Map Units

All map units in a soil survey are named. Different conventions are used for each of the four kinds of map units so that the kind of unit can be determined at a glance. In general, names are as short as is practical; the name of a map unit should be only as long as is necessary to distinguish it from all others in the survey. At times an extra term, not needed to dis-

tinguish a phase from all others in the survey, is used so that comparable phases in other areas have the same name.

Although some of the conventions for naming map units are discussed in this chapter, a more complete discussion is provided in the *National Soils Handbook* (Soil Conservation Service). Soil names indicate the categorical level used for identification, but soil taxonomic names are never used alone.

Phases are groupings created to serve specific purposes in individual soil surveys. Phases can be defined for any class or classes of any category. The classes are helpful in describing the soil phases that are important for the survey. Differences in soil or environmental features that are significant to use, management, or behavior are the bases for designating soil phases.

Any property or combination of properties that does not duplicate class limits for a taxon can be used to differentiate phases, and any value of a property can be set to divide phases. The choice of properties and limits are determined by the purpose of the survey and by how consistently the phase criteria can be applied. Because objectives differ from one soil survey to another, limits and ranges of a property or attribute may also differ from one survey to another. In general, phase criteria are given a smaller range where soil use is intensive (as for irrigated farming or urban development) and a larger range where use is extensive (as for forestry or grazing).

The attributes most commonly used in defining phases in soil surveys are:

Texture of the surface layer.—As the surface layer has special significance for use of the soil, texture of the surface layer is commonly indicated in the names of consociations bearing the names of soil series. These phases generally identify the dominant texture of a mineral layer about equal in thickness to that commonly mixed in tillage, which is generally 12 to 25 cm. If the layer has not been mixed, the texture that would be produced by mixing is estimated. If, after mixing, the layer is organic, terms for organic material are used to name the phase. In some areas such as deserts, where the surface layer is normally thin and cultivation is unlikely, the texture of the A horizon can be used in naming phases even if it is less than 12 cm thick.

Some mineral soils have a thin layer at the surface that contrasts sharply with the next layer. Such soils may be designated as separate phases if they are unlikely to be tilled and if clearly significant to use or management. On rangeland, for example, the texture of the uppermost few centimeters of soil is important. A thin layer of sandy material at the surface may mean the difference between success and failure of seedings

on some soils. For some surveys, such layers need to be recognized and their areas delineated. Moreover, a thin cover of silt or clay is an important distinction.

Conceivably, other kinds of phases based on texture could be useful in mapping, but they should be used only if the indicated property has a major and lasting effect on interpretations.

Deposits on the surface.—Some soils have received deposits of material thick enough to influence interpretations of the soil but not thick enough to change the classification. Depositional phases of the buried soils may be recognized:

> **Overblown:** A recent deposit of wind-blown material on the surface of an older soil can be identified consistently throughout the area and is thick enough to influence use, management, or behavior.
>
> **Wind hummocky:** Recent wind-laid deposits form a fine pattern of hummocks that markedly alter management requirements of the soil. The original soil is identifiable throughout most of the area, although it is covered in spots.
>
> **Overwash:** Material deposited by water that contrasts with the underlying soil and is thick enough to influence management requirements significantly. Ordinarily, overwash phases are not used for very young alluvial soils that have weakly expressed genetic horizons.

Texture terms in the names of map units describe the material currently at the surface. Phases may be recognized for soils covered by a thin layer of volcanic ash. Such phases are generally used only if needed to distinguish the phase from another phase that lacks the ash cover.

Rock fragments.—Rock fragments at the surface and in the surface layer are commonly used as phase distinctions. Kinds of rock fragments are defined by shape and size in chapter 3.

Phases of the smaller rock fragments accommodate most of the detailed phase distinctions that generally can be made accurately by field methods. The term "gravelly" is used in the examples of the names that follow, but the adjectives for each of the other kinds of rock fragments, such as cobbly or channery, are substituted as appropriate. The effect of 20 percent fine gravel on the use of arable soil, for example, is quite different from the effect of 20 percent flagstones; therefore, the phase limits may differ for larger fragments.

The following definitions are applicable to arable soils. For other uses—such as forestry, range, or recreation—the sizes, shapes, amounts, and mixtures of rock fragments have different significance. Pebbles, cobbles, and stones influence forestry much less than they do cultivation, although they could affect access and reforestation.

Nongravelly. The surface layer may contain enough pebbles to affect special uses that tolerate few if any rock fragments, but the pebbles do not interfere with the tillage of such field crops as corn. The volume is less than 15 percent. A slightly gravelly phase can be recognized for soils that are used for special purposes, such as growing turf.

Gravelly. The surface layer contains enough pebbles to interfere with tillage of common field crops. Generally, however, tillage is performed in the same manner and with the same equipment as for soils free of fragments. The pebbles are a nuisance. They may cause some equipment breakage, but they cause few major delays in field operations. The effects of the pebbles on the quality of tillage are small or moderate, depending on the kind of operation. The volume of pebbles is 15 to 35 percent.

Very gravelly. The surface layer contains enough pebbles to interfere seriously with the tillage of common field operations. The quality of tillage operations is affected. The kinds of crops that can be grown is restricted, the precision of planting and of fertilizer placement is reduced, and young plants are frequently covered during tillage. The volume of pebbles is 35 to 60 percent.

Extremely gravelly. The surface layer contains so many pebbles that tillage of the common field crops is often impractical, although not necessarily impossible. Tillage implements must force their way through a mass of pebbles that have fine earth between them. The volume of pebbles is more than 60 percent.

The rock fragments in the surface layer commonly span two or more size classes. The included fragments may be of more than one shape. The name of the kind of fragment that is judged most important in limiting the management of the soil is used in the phase designation. Generally, the largest fragments that are present in significant amounts are the most restrictive on soil use.

Classes of stoniness and boulderiness (chapter 3) are also used to define phases. The following phases of the larger rock fragments represent about the maximum detail that can be mapped consistently in most soil surveys. "Bouldery" is substituted for "stony" as appropriate.

Stony. The areas have enough stones at or near the surface to be a continuing nuisance during operations that mix the surface layer, but they do not make most such operations impractical. Conventional, wheeled vehicles can move with reasonable freedom over the area. Stones may damage both the equipment that mixes the soil and the vehicles that move on the surface. Usually, these areas have class 1 stoniness. If necessary in a highly detailed survey, these areas may be designated as "slightly stony" and "moderately stony."

Very stony. The areas have so many stones at or near the surface that operations which mix the surface layer either require heavy equipment or use of implements that can operate between the larger stones. Tillage with conventionally powered farm equipment is impractical. Wheeled tractors and vehicles with high clearance can operate on carefully chosen routes over and around the stones. Usually, these areas have class 2 stoniness.

Extremely stony. The areas have so many stones at or near the surface that wheeled powered equipment, other than some special types, can operate only along selected routes. Tracked vehicles may be used in most places, although some routes have to be cleared. Usually, these areas have class 3 stoniness.

Rubbly. The areas have so many stones at or near the surface that tracked vehicles cannot be used in most places. Usually, these areas have class 4 or 5 stoniness. If necessary in a highly detailed survey, they may be designated as "rubbly" and "very rubbly."

If the soil has stones, boulders, and smaller fragments, the name includes the kind of rock fragment that are most limiting in the use or management of the soil. This is not necessarily the kind that is most abundant or the kind that is used to modify texture class of horizons in the profile description.

Rockiness. Map units, consisting of about 0.1 to 10 percent Rock outcrop, can be named either as "rocky" phases or as complexes or associations of soil and Rock outcrop. Map units consisting of more than 10 percent outcrop are normally named as complexes or associations

of soil and Rock outcrop. Where rockiness phases are used, both "rocky" and "very rocky" phases can be named. Commonly, map units with less than 2 percent Rock outcrop are named "rocky" and those with 2 to 10 percent "very rocky."

Slope. The slope range of some soil taxa is narrow; in others, it is wide enough to include differences that are important for soil use and management. Slope phases are used to divide soil series or other taxa as may be needed for the purpose of the survey.

Slope gradient, complexity, shape, length, and aspect are all potential bases for phase distinctions. By far the most commonly used is gradient. Complexity is also used in many surveys. Slope length can often be appraised directly from delineations on the map. In many cases, the significance to use and management of slope length depends on the kind of landscape in which the soil occurs. Shape is seldom used as a phase distinction; differences in shape are commonly related to differences in internal properties that distinguish taxa. Slope aspect is used mainly in high latitudes.

Phases defined on the basis of slope should fit the landscape. They should be so distinct that they can be identified and mapped consistently without adding useless complexity to the map. In addition, such phases should separate areas that have significant differences in suitability or management needs.

A uniform system of slope classes should not be used indiscriminately as the basis for differentiating phases. Slope phases that have narrow ranges in gradient may be needed for soils that can be used intensively. For other soils having additional limitations, such as stoniness, these narrow ranges may be useless. The limits of slope phases should be based on data or experience in order to indicate the most useful distinctions for each kind of soil. Range in the slope of a phase of one series may encompass the ranges of two or more phases of another series. A single set of slope classes that would serve as phase distinctions for all soils is impractical because of the varied relationships of slope to mappable landscapes and to the use and management of different kinds of soils.

Table 3-1 defines slope classes in terms of flexible limits for both simple and complex slopes. The flexible limits permit use of terms to identify most distinctions of slope that may be needed. Names may use either numerical gradient limits, with or without designations of complexity, or descriptive terms. Slope terms for map units for taxa above the series are generally given in descriptive terms. The word "slopes" is used if gradient is specified as a percentage, but it is omitted if descriptive terms are used.

Depth.—Soil depth phases are used where variations in depth to a contrasting layer are significant to soil use, management, or behavior. Terms for depth classes in Chapter 3 are generally used in naming phases, but modifications are needed in some areas. For instance, the class "moderately deep," ranging from 50 to 100 cm, may be too broad to satisfy the objective of a particular survey. This range can be divided, with perhaps one class ranging in depth from 50 to 75 cm and the other from 75 to 100 cm, if the more narrowly defined phases occur in a consistent pattern within the survey area and can be mapped. Generally, the phase that covers the least acreage is given the depth designation. If the deeper phase is more extensive, "moderately shallow" is used to designate the shallower phase. If the shallower phase is more extensive, "moderately deep" is used to designate the deeper phase.

In some surveys, using the standard class terms may be misleading. For example, if a series that is normally more than 175 cm deep to bedrock has a phase that is 150 to 175 cm deep, calling the less extensive phase "deep" could be construed to mean that the phase is deeper than normal. In such cases, depth limits can be specified in the phase name, or substratum phase terminology can be used instead.

Substratum.—Where underlying material contrasts sharply with the material above and interpretations are affected, substratum phases are used. The kind of contrasting material is indicated in the name of the map unit. Some examples of commonly used substratum phases are: *gravelly substratum, sandy substratum, silty substratum, shale substratum, till substratum.* These terms are descriptive and not mutually exclusive. Where there is a choice between using a depth phase or a substratum phase to identify a map unit, a depth phase is generally used if the contrasting layer is bedrock.

Soil water.—Phases are used to distinguish differences in soil-water state, water table level, drainage, and the like where the range of the taxon in one or more of these properties needs to be divided for purposes of the survey. Significant differences in these factors are commonly reflected in differences in soil morphology and are distinguished at the series level. In some soils, however, evidence of wetness, such as redoximorphic features, does not fully reflect the natural drainage or wetness of the soil. These soils may not be differentiated at the series level with the refinement needed for the purposes of the survey.

Examples of soil water phases commonly used are: *high water table, poorly drained, slightly wet*, and *drained*. Some soils have properties that reflect former wetness, but they have been drained artificially; "drained" phases can be used to separate drained areas from undrained. In other soils, a water table fluctuates below the depth

where properties are criteria for defining series; "water table" phases can be used to identify such soils.

Salinity.—Saline phases are used to distinguish between degrees of salinity that are important for soil use or management. Electrical conductivity values and observations of plant growth are guides for recognizing phases.

Designation of salinity phases depends on the various uses likely to be made of the soils and the effect of excessive amounts of salt on the uses. In farming areas, the crops most likely to be grown must be considered. Management induced salinity that fluctuates widely with management practices generally would not be a basis for phase distinctions.

Vegetation, especially the native cover, often shows the location of saline soils and their boundaries. Using vegetation, landform, and other features as guides and correlating these field observations with laboratory or field analyses of soil samples, the surveyor can usually draw boundaries with reasonable accuracy. Plants, however, vary in their tolerance of salt by species, variety, age, and perhaps other factors. Some plants are not good indicators of salinity because they grow well in soils that may have excessive amounts.

Other problems must also be considered in designating salinity phases. Different kinds of salts and combinations of salts have varied effects on soil behavior. In many soils, salts are transitory; in others, they are permanent. Excessive sodium may or may not be associated with excess salinity.

The following classes of salinity, which are a general guide to naming phases, refer to the presence of salts in the soil. Salinity classes are defined in chapter 3.

> **Nonsaline:** Effects of salinity on plant growth are negligible. Salinity is mainly class 0 and 1. "Nonsaline" is omitted from the names of mapping units unless the soil taxon is typically saline. A very slightly saline phase may be useful in some surveys for crops extremely sensitive to salts.

> **Slightly saline:** Growth of many plants is affected. Yields of such plants as bromes, sunflower, corn, and peas are reduced seriously. Western wheatgrass, kale, and barley are affected little. Salinity is mainly class 2.

> **Moderately saline:** Only plants tolerant of salinity, such as western wheatgrass, beets, and barley, grow well. Yields of these are commonly reduced. Salinity is mainly class 3.

> **Strongly saline:** Only the most tolerant halophytic plants, such as saltgrass, grow well. Salinity is mainly class 4.

Terms for saline phases follow terms for surface texture in phase names.

Sodicity.—For some soils, recognizing a "sodic" phase is useful. The term "sodic" is used as a phase designation, if needed, generally without terms for degrees of sodicity.

Physiography.—Landform or physiographic position may be used as a phase criterion to distinguish phases of a single taxon. A soil in a deposit of loess 3 meters thick on a terrace, for example, may be so much like a soil in a similar deposit on a till plain that the two are members of the same taxon. For some uses, however, the two soils need to be distinguished on the map. A physiographic phase can be used to identify the less extensive soil.

Examples of terms that have been used to designate physiographic phases are: *bench*, *depressional*, *fan*, *karst*, *ridge*, and *terrace*. The terms generally identify phases that differ in position from what is typical for the soil. The typical physiography is not given in a phase name. The physiographic phase designation follows the term for surface texture and precedes any terms for slope or erosion.

Erosion.—Differences in soil potential for use, management needs, or performance because of accelerated erosion are a basis for recognizing phases. Phases of eroded soil are identified on the basis of the properties of the soil that remains, although the amount of soil lost is estimated and noted. In some places, erosion has changed the taxonomic classification of a soil.

Properties related to natural erosion are a part of the definition of a taxon, not bases for erosion phases. Erodibility, too, is an inherent quality of a soil and not itself a criterion for erosion phases.

Eroded phases are defined so the boundaries on the soil maps separate soil areas of unlike suitabilities and soil areas of unlike management needs and responses.

Guidelines for naming phases of soil that are eroded by water are as follows. Erosion classes are defined in chapter 3.

> **Slightly eroded:** Erosion has changed the soil enough to require only slight modification of management from that of the uneroded soil; potential use and management remain generally the same. Most slightly eroded soils have class 1 erosion. Slightly eroded areas are not distinguished from uneroded areas in most surveys.

Moderately eroded: Generally, the plow layer consists of a mixture of the original A horizon and the underlying horizons. Most mapped areas of moderately eroded soils have patches in which the plow layer consists wholly of the original A horizon and others in which it consists wholly of underlying horizons. Shallow gullies may be present in some places. Erosion has changed the soil to such an extent that required management or the response to management differs in major respects from that of the uneroded soil. In most moderately eroded soils, ordinary tillage implements reach through the remaining A horizon or well below the depth of the original plowed layer. Most moderately eroded soils have class 2 erosion.

Severely eroded: Severely eroded phases commonly have been eroded to the extent that the plow layer consists essentially of material from underlying horizons. Patches in which the plow layer is a mixture of the original A horizon and underlying horizons may be present within some delineations. Shallow gullies, or a few deep ones, are common in some places. Erosion has changed the soil so much that (1) the eroded soil is suited only to uses significantly less intensive than the uneroded soil, such as use for pasture instead of crops, (2) the eroded soil needs intensive management immediately or over a long period to be suitable for the same uses as the uneroded soil; (3) productivity is reduced significantly; or (4) limitations for some major engineering interpretations are greater than on the uneroded soil. Most severely eroded soils have class 3 erosion.

A "gullied" phase can be recognized if gullied land occupies less than about 10 percent of the map unit. Gullied phases are used for areas having gullies so deep that intensive measures, including reshaping, are required to reclaim the soil. Where the areas are more than 10 percent gullied land, the map units are named as complexes or associations of soil and gullied land.

Guidelines for designating phases of soil eroded by wind are as follows:

Eroded (blown): Wind has removed enough soil that required management differs significantly from that of the uneroded soil, but suitabilities for use remain the same. The term "moderately" is understood.

Severely eroded (severely blown): Wind has removed much of the soil or has shifted it from place to place within the area. Suitability for use is different from that of the uneroded soil, unless extensive reworking is done and/or intensive management practices are used.

Many areas identified as moderately and severely wind eroded are, in fact, mixtures of small areas of uneroded soil and soil eroded to various degrees. The amount of erosion throughout a delineation can be described only in general terms.

Thickness.—The solum and the various horizons in soil have characteristic ranges in thickness for each taxon. Thickness phases may be used to divide the range of thickness of the solum or of the upper horizons. Phases are not used to differentiate thickness of the subsoil or the substratum. Four thickness phases are used:

Thick surface: The thickness of the A horizon or of the A and E horizons combined is within the thicker half of the range for the taxon.

Thin surface: The thickness of the A horizon or of the A and E horizons combined is within the thinner half of the range for the taxon.

Thick solum: The thickness of the solum is within the thicker half of the range for the taxon.

Thin solum: The thickness of the solum is within the thinner half of the range for the taxon.

A term is used for the less extensive of two thickness phases. For example, most delineations of a given soil may have an A horizon that is dominantly between 25 and 35 cm thick. If the A horizon is dominantly 35 to 40 cm thick in other delineations of the same soil and the difference is significant for purposes of the survey, a thick-surface phase can be recognized. The phase in which the A horizon is dominantly 25 to 35 cm thick is the norm; thickness of the A horizon is described for this phase but is not identified in the name.

Climate.—In some places, especially in mountainous or hilly areas, precipitation or air temperature can differ greatly within short distances, yet these differences may not be reflected in internal properties of the soil. Air drainage can differ enough from one location to another to produce a difference in the dates of the last killing frost in the spring or the first in the fall, or one area may be frost free. Climatic phases are used for these situations.

Only two climatic conditions are recognized for a given taxon: (1) the common climate, the climate that influences the greatest extent of the taxon, from which the climate designation is omitted, and (2) a departure from the common climate, for which a climatic designation is used.

The departure may be in either of two directions from the norm: *warm* or *cool, high precipitation* or *low precipitation*. Each of the terms is connotative only in reference to the common climate of the taxon and must be described specifically for each phase to which it is applied.

In many places, especially on plains, precipitation or temperature changes gradually over distance. A soil in a single survey area commonly includes only part of the range for the series. Climatic phases generally are not used if only part of the range is within a soil survey area. Climatic phases are local distinctions. They are used where temperature or precipitation differs markedly between parts of a survey area.

Other.—A great variety of phase distinctions can be made. In addition to those already described, others may be needed to provide suitable map units; for example: *frequently flooded, occasionally flooded, burned, calcareous, leached surface, dark surface.* "Burned," for example, might be used for organic soils that have lost enough of their organic material by fire to alter their potential use or their management requirements.

The phases designated by special terms are defined to fit special kinds of soils. Such phases are defined according to the common properties of the taxon of which they are members. Thus, the terms usually have different specific meanings when used for different taxa and in different survey areas.

Miscellaneous Areas

Miscellaneous areas have essentially no soil and support little or no vegetation. This can be a result of active erosion, washing by water, unfavorable soil conditions, or man's activities. Some miscellaneous areas can be made productive but only after major reclamation efforts. Map units are designed to accommodate miscellaneous areas, and most map units named for miscellaneous areas have inclusions of soil. If the amount of soil exceeds the standards for inclusions defined in this chapter, the map unit is named as a complex or association of miscellaneous area and soil.

Following are discussions of recognized kinds of miscellaneous areas.

Badland is moderately steep to very steep barren land dissected by many intermittent drainage channels. Ordinarily, the areas are not stony. Badland is most common in semiarid and arid regions where streams cut into soft geologic material. Local relief generally ranges between 10 and 200 meters. Potential runoff is very high, and erosion is active.

Beaches are sandy, gravelly, or cobbly shores washed and rewashed by waves. The areas may be partly covered with water during high tides or storms.

Blown-out land consists of areas from which all or most of the soil material has been removed by extreme wind erosion. The areas are generally shallow depressions that have flat or irregular floors. In some places the floor is a layer of material that is more resistant to wind than the removed material or is a layer of pebbles or cobbles; or, the floor may have been formed by exposure of the water table. Areas covered by water most of the year are mapped as Water. Some areas have a few hummocks or small dunes. Few areas of blown-out land are large enough to be delineated; small areas can be shown by spot symbols.

Cinder land is composed of loose cinders and other scoriaceous magmatic ejecta. Water-holding capacity is very low, and trafficability is poor.

Cirque land consists of areas of rock and rubble in characteristically cirque shape. The shape is caused by glacial erosion.

Dumps are areas of smoothed or uneven accumulations or piles of waste rock and general refuse. Dumps, mine consist of areas of waste rock from mines, quarries, and smelters. Some dumps with closely associated pits are mapped as Dumps-Pits complex.

Dune land consists of sand in ridges and intervening troughs that shift with the wind.

Glaciers are large masses of ice formed, at least in part, on land by the compaction and recrystallization of snow. They may be moving slowly downslope or outward in all directions because of the stress of their own weight; or, they may be retreating or be stagnant. A little earthy material may be on or in the ice.

Gullied land consists of areas where erosion has cut a network of V-shaped or U-shaped channels. The areas resemble miniature badlands. Generally, gullies are so deep that extensive reshaping is necessary for most uses. Small areas can be shown by spot symbols. Phases indicating the kind of material remaining may be useful in some places.

Gypsum land consists of exposures of nearly pure soft gypsum. The surface is generally very unstable and erodes easily. Trafficability is very poor. Areas of hard gypsum are mapped as Rock outcrop.

Lava flows are areas covered with lava. In most humid regions, the flows are of Holocene age, but in arid and very cold regions they may be older. Most flows have sharp, jagged surfaces, crevices, and angular blocks characteristic of lava. Others are relatively smooth and have a ropy glazed surface. A little earthy material may be in a few rocks and sheltered pockets, but the flows are virtually devoid of plants other than lichens.[2]

Oil-waste land consists of areas where liquid oily wastes, principally saltwater and oil, have accumulated. It includes slush pits and adjacent areas affected by the liquid wastes. The land is barren, although some of it can be reclaimed at high cost.

Pits are open excavations from which soil and commonly underlying material have been removed, exposing either rock or other material. Kinds include Pits, mine; Pits, gravel; and Pits, quarry. Commonly, pits are closely associated with Dumps.

Playas are barren flats in closed basins in arid regions. Many areas are subject to wind erosion and many are saline, sodic, or both. The water table may be near the surface at times.

Quarries (see Pits).

Riverwash is unstabilized sandy, silty, clayey, or gravelly sediment that is flooded, washed, and reworked frequently by rivers.

Rock outcrop consists of exposures of bare bedrock other than lava flows and rock-lined pits. If needed, map units can be named according to the kind of rock: *Rock outcrop, chalk; Rock outcrop, limestone; Rock outcrop, gypsum*. Many rock outcrops are too small to be delineated as areas on soil maps but can be shown by spot symbols. Some areas are large, broken by only small areas of soil. Most rock outcrops are hard rock, but some are soft.

Rubble land consists of areas of cobbles, stones, and boulders. Rubble land is commonly at the base of mountains but some areas are deposits of cobbles, stones, and boulders left on mountainsides by glaciation or by periglacial processes.

Salt flats are undrained flats that have surface deposits of crystalline salt overlying stratified very strongly saline sediment. These areas are closed basins in arid regions. The water table may be near the surface at times.

Scoria land consists of areas of slaglike clinkers, burned shale, and fine-grained sandstone remaining after coal beds burn out. (Scoria land should not be confused with volcanic slag.)

Slickens are accumulations of fine-textured material, such as that separated in placer-mine and ore-mill operations. Slickens from ore mills consist largely of freshly ground rock that commonly has undergone chemical treatment during the milling process. Slickens are usually confined in specially constructed basins.

Slickspots are areas having a puddled or crusted, very smooth, nearly impervious surface. The underlying material is dense and massive. The material ranges from extremely acid to very strongly alkaline and from sand to clay.

Urban land is land mostly covered by streets, parking lots, buildings, and other structures of urban areas.

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[2] Lava flows in very wet climates that support a nearly continuous plant cover, even though the amount of fine earth is small, are classified as soil and not as lava flows. Some soils of this kind have been in place for less than 100 years.

Water includes streams, lakes, ponds, and estuaries that in most years are covered with water at least during the period warm enough for plants to grow; many areas are covered throughout the year. Pits, blowouts, and playas that contain water most of the time are mapped as *Water*.

Records and Definitions of Soil Taxa

Keeping definitions and names of soil taxa up to date is essential for identification of map units, for correlation of soils nationwide, and for transfer of information about soils at one place to similar kinds of soil elsewhere.

Definitions and names of soil taxa can be kept by different methods. The methods used are modified from time to time. Some kind of centralized system is needed to obtain a nationwide perspective, to maintain standards for defining soil taxa, to assemble field and laboratory data, and to disseminate information to the field.

Soil Series Definitions

Soil series are used for naming most map units of soil surveys in the United States. Over time, the concepts of the series category and of individual series have changed, but more than 16,000 series are now defined and named. These definitions are the framework within which most of the detailed information about soils of the United States is identified with soils at specific places. These definitions also provide the principal medium through which detailed information about the soil and its behavior at one place is projected to similar soils at other places.

Rigorous standards for definitions of soil series ensure that names and descriptions for the same kinds of soils are consistent from survey to survey. Consistency is a major objective of the correlation process. The classes of the soil series category are not static. As new knowledge is acquired, definitions of some established series must be modified. New series are defined for newly recognized kinds of soils. Changes in criteria or limits of taxa in higher categories often require modification of definitions of member series.

Keeping records of series names and updating definitions of series is a continuing process. The changes should be accomplished in ways that detract the least from the predictive value associated with the earlier definitions and names. A centralized system for keeping records of soil series names and definitions ensures that names and definitions of soil series meet the rigorous standards needed in a national soil survey program.

Official soil series descriptions.—Each soil series must be defined as fully and accurately as existing knowledge permits. This applies to proposed soil series used in an individual survey as well as to established series. To ensure the inclusion of essential information and to permit comparison of series definitions, a standard format for recording specific kinds of information is used.

Official soil series descriptions record definitions of soil series and other relevant information about each series. The format, the kind, and the amount of detail may change from time to time, but detailed definition and a series interpretation record are essential. General, descriptive information is also needed to aid the reader in identifying the soil in the landscape and relating it to other kinds of soil.

An official soil series description should include at least the following:

1. Full taxonomic name of the family taxon for which it is a member. This indicates the classes that provide limits of properties that are diagnostic for the series at all categorical levels, except for those between series of the same family.

2. A description of a typical pedon and its horizons, describing each in as much detail as necessary to recognize its taxonomic class. Horizons that are diagnostic for the pedon must be described.

3. A statement of the ranges of properties of the series. This section also contains statements about the relationship of the series control section and diagnostic horizons to vertical subdivisions of the typical pedon.

4. A statement distinguishing the series from "competing series" with which it might be confused. Competing series are mainly those that share common limits with the series described or are members of the same family.

5. A statement that identifies at least one specific place that represents a norm for the series—a "type location." A type location should be described accurately enough so that it can be located in the field.

Descriptive parts of an official soil series description are not required to define the series, but they aid the reader. All parts are not equally important for all soils. Many descriptions include the following:

1. Landform and physiographic position of the series, including its position relative to other landscape elements with which it is associated.

2. Evolution of the landscape. Influences of the soil-forming factors on the genesis of the series should be identified.

3. Parent-material: The kind of mineral or organic material in which the soil formed, including kinds of rock from which the regolith was derived if that can be determined.

4. Drainage of the soil by drainage class or other means of description relative to soil moisture regimes. Seasonal wetness or dryness may be important.

5. Other kinds of soil with which the series is closely associated geographically.

6. Major uses of the soil and dominant kinds of vegetation that grow on it. Native plants are identified, if known.

7. Rationale for classification. Implicit assumptions related to family classification may be described when laboratory data are not available.

8. Distribution and extent: the known geographic distribution and whether the soil occupies a large, small, or intermediate aggregate area.

9. Year and the survey area where the series was proposed or established.

10. Name of the person who prepared and approved the series description and the date it was prepared or approved.

11. References to available laboratory data.

12. Interpretations for common uses of the soil.[1]

Other taxa

Soil series identified in individual surveys are classified in specific taxa of higher categories. The limits of most properties of soil series are set by the limits of the higher taxa in which they are classified. Soil Taxonomy (Soil Survey Staff, 1975) is the basic reference book for identification, classification, nomenclature, and correlation of kinds of soils for categories above the series.

During a survey, the taxonomic system is tested and retested many times. The results of these tests are reported at field reviews and at the field correlation. Problems in mapping or identifying soils and inconsistencies between the system and observed properties of the soils are recorded in field review reports and correlation memoranda. After appraising these reports, supervisory soil scientists call any inadequacies to the attention of the office responsible for keeping the system up to date.

Orders of Soil Surveys

All soil surveys are made by examining, describing, and classifying soils in the field and delineating their areas on maps. Some surveys are made to serve users who need precise information about the soil resources of areas a few hectares or less in size. These surveys require refined distinctions among small, homogeneous areas of soil. Others are made for users who need a broad perspective of heterogeneous, but distinctive, areas of thousands of hectares. A soil survey made for one group of users may not serve the other group well.

The elements of a soil survey can be adjusted to provide the most useful product for the intended purposes. Different intensities of field study, different degrees of detail in mapping, different phases or levels of abstraction in defining and naming map units, and different map unit designs produce a wide range of soil surveys. Adjustments in these elements form the basis for differentiating five orders of soil surveys (table 2-1).

Recognition of these different levels of detail is helpful for communicating about soil surveys and maps, even though the levels cannot be sharply separated from each other. The orders are intended to aid in the identification of the operational procedures used to conduct a soil survey. They also indicate general levels of the quality control that is

[1]Methods and conventions for developing and displaying soil series interpretations will be described in chapter 6.

TABLE 2-1

Key for Identifying Kinds of Soil Surveys

Level of data needed	Field procedures	Mininum-size delineation (hectares)[1/]
1st order- Very intensive (i.e., experimental plots, individual building sites)	The soils in each delineation are identified by transecting or traversing. Soil boundaries are observed throughout their length. Remotely sensed data are used as an aid in boundary delineation.	1 or less
2nd order - Intensive (i.e., general agriculture, urban planning)	The soils in each delineation are identified by field observations and by remotely sensed data. Boundaries are verified at closely spaced intervals.	0.6 to 4
3rd order - Extensive (i.e., range, community planning)	Soil boundaries plotted by observation and interpretation of remotely sensed data Soil boundaries are verified by traversing representative areas and by some transects.	1.6 to 16
4th order - Extensive (general soil information for broad statements concerning land-use potential and general land management)	Soil boundaries plotted by interpretation of remotely sensed data. Boundaries are verified by traversing representative areas and by some transects.	16 to 252
5th order - Very extensive (i.e., regional planning, selections intensive study)	The Soil patterns and composition of map units are determined by mapping representative ideas and like areas by interpretation of remotely sensed data. Soils verified by occasional onsite investigation or by traversing.	252 to 4,000

[1/] This is about the smallest delineation allowable for readable soil maps (see table 2-2). In practice, the minimum-size delineations are generally larger than the minimum-size shown.

TABLE 2-1 (continued)

Typical components of map units	Kinds of map units[2]	Appropriate scales for field mapping and publications
Phases of soil series, miscellaneous areas.	Mostly consociations, some complexes, miscellaneous areas.	1:15,840 or larger
Phases of soil series, miscellaneous areas, few named at a level above the series.	Consociations, complexes; few associations and undifferentiated groups.	1:12,000 to 1:31,680
Phases of soil series or taxa above the series; or miscellaneous areas.	Mostly associations or complexes, some consociations and undifferentiated groups.	1:20,000 to 1:63,360
Phases of soil series of taxa above the series or miscellaneous areas.	Mostly associations; some complexes, consociations, and undifferentiated groups.	1:63,360 to 1:250,00
Phases of levels above the series, miscellaneous areas.	Associations; some consociations and undifferentiated groups.	1:250,000 to 1:1,000,000 or smaller

[2] Where applicable, all kinds of map units (consociations, complexes, associations, undifferentiated units) can be used in any order of soil survey.

applied during the survey. These levels affect the kind and precision of subsequent interpretations and predictions. The orders differ in the following elements:[4]

I. The soil survey legend, including

- the kinds of map units: consociations, complexes, associations, and undifferentiated groups, and
- the kinds of soil taxa for identifying the map units: soil series, families, subgroups, great groups, suborders, and orders, and phases of them;

II. The standard for purity of delineated soil areas, including

- the minimum area of a limiting dissimilar soil that must be delineated separately and thus excluded from areas identified as another kind of soil, and
- the maximum percentage of limiting dissimilar inclusions that is permissible in a map unit;

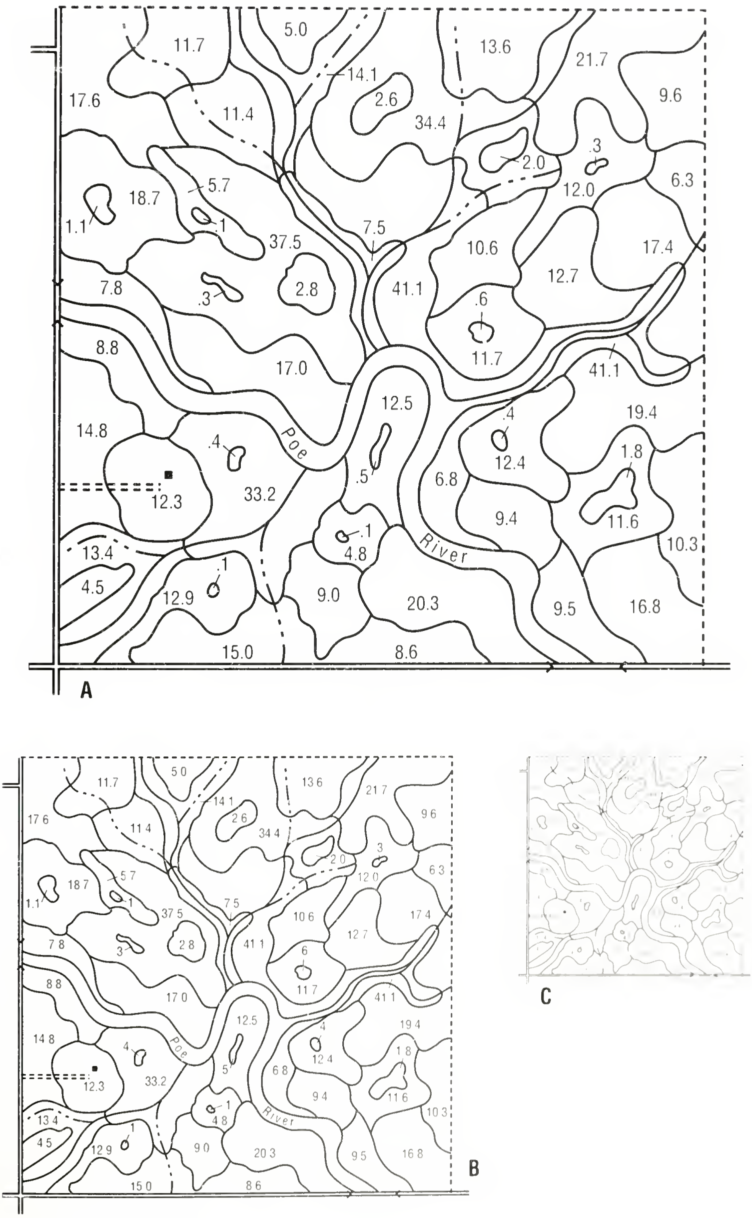
III. The field operations necessary to identify and delineate areas of the map units within prescribed standards of purity; and

IV. The minimum map scale required to accommodate the map units of the legend, the standards of purity, and the map detail justified by field methods.

Mapping legends are designed to provide the degree of refinement of map units required by the objectives of the survey. A map unit can be identified as a consociation (an area dominated by a soil of a single taxon such as a series or a suborder) or as a group (geographic mixture) of taxa, such as associations or complexes. A group may be more heterogeneous, and less refined, than a consociation at the same level of classification. A soil series has a much more narrowly defined set of soil properties than a suborder; and, therefore, it is a more refined distinction. Thus, phases of soil series are used as map units if users need more precise information about small areas of soils. Phases of any category in *Soil Taxonomy* might

[4]"Delineations," "map units," "phase," "complex," "consociation," "association," "group," "similar soils," "dissimilar soil," "limiting dissimilar soil," and "inclusion" are explained in chapter 2. Soil survey legends, maps, and map scales are discussed in chapter 4. Chapter 5 explains information-recording procedures. The levels of soil classification are explained in chapter 5 of *Soil Taxonomy*.

FIGURE 2-4



Copies of the same map at different scales: A, 1:21,120; B, 1:31,680; C, 1:63,360 (equivalent to 3, 2, and 1 inch equals one mile, respectively). The numbers within individual delineations are the acreages of the areas represented (1 acre equals 0.40 hectares).

be used as soil map units if a very broad perspective of the soil resources of very large areas is needed.

Standards of *purity* are adjusted according to the precision required by the survey objectives. Probably all delineations contain some kinds of soil besides that identified in the map unit name. These inclusions reduce purity. Different kinds of inclusions, however, have different effects on the value of the map for use. The inclusions that most detract from purity are those that are distinctly more limiting for use than the named soil. These are called limiting dissimilar soils. Not only the amount of such limiting soils but also the size of their individual areas is important. Soil survey standards for both are set at levels that do not seriously detract from the validity of interpretations based on the named soil.

Standards of purity are attained by adjusting the field operations. If the standards require that areas of limiting dissimilar soils as small as 0.1 ha be delineated, for example, the area must be traversed at intervals close enough to find areas that small and the soil must be examined at enough places along each traverse to detect them.

The *map scale* must be large enough to allow areas of minimum size to be delineated legibly. Figure 2-4 illustrates the effect of scale on legibility of maps.

The choice of map scale also depends on the perspective of the user. Users who need precise information about small areas focus their attention on a small part of the map and on a relatively few delineations. They are not distracted by boundaries and symbols on other parts of the map. Consequently, the map scale can be the smallest that will permit legible delineation of the pertinent areas.

Map users who want a broad perspective of large areas, however, are usually concerned with comparisons among delineations of all, or a large part, of the map. Consequently, delineations on maps for such uses are generally larger and fewer in number.

Table 2-2 shows the relationships between map scales and the smallest delineations that can be made legibly at those scales. The difference between the smallest delineation that could be made and the smallest that is commonly made increases as map scale decreases.

The order of a survey is a consequence of field procedures, the minimum size of delineation, and the kinds of map units that are used. Table 2-1 is a key for identifying orders of soil surveys.

First-order surveys are made for very intensive land uses requiring very detailed information about soils, generally in small areas. The information can be used in planning for irrigation, drainage, truck crops, citrus or other specialty crops, experimental plots, individual building

TABLE 2-2

Guide to Map Scales and Minimum Delineation Size

Map scale	Inches per mile	Minimum size delineation[1] acres	hectares
1:500	126.7	0.0025	0.001
1:2,000	31.7	0.040	0.016
1:5,000	12.7	0.25	0.10
1:7,920	8.00	0.62	0.25
1:10,000	6.34	1.00	0.41
1:12,000	5.28	1.43	0.57
1:15,840	4.00	2.5	1.0
1:20,000	3.17	4.0	1.6
1:24,000 (7 1/2')	2.64	5.7	2.3
1:31,680	2.00	10.0	4.1
1:62,500 (15')	1.01	39.0	15.8
1:63,360	1.00	40.0	16.2
1:100,000	0.63	100.0	40.5
1:125,000	0.51	156.0	63.0
1:250,000	0.25	623.0	252.0
1:300,000	0.21	897.0	363.0
1:500,000	0.127	2,500.0	1,000.0
1:750,000	0.084	5,600.0	2,270.0
1:1,000,000	0.063	10,000.0	4,000.0
1:5,000,000	0.013	249,000.0	101,000.0
1:7,500,000	0.0084	560,000.0	227,000.0
1:15,000,000	0.0042	2,240,000.0	907,000.0
1:30,000,000	0.0021	9,000,000.0	3,650,000.0
1:88,000,000	0.0007	77,000,000.0	31,200,000.0

[1]The "minimum size delineation" is taken as a 6-mm square area (1/16 sq. in). Cartographically, this is about the smallest area in which a symbol can be printed readily. Smaller areas can be delineated, and the symbol lined in from outside; but such small delineations reduce map legibility. On maps at the smaller scales, delineations are commonly 1 1/2 to 2 times the size of the minimum area that can be shown.

sites, and other uses that require a detailed and very precise knowledge of the soils and their variability.

Field procedures permit observation of soil boundaries throughout their length. The soils in each delineation are identified by traversing and transecting. Remotely sensed data are used as an aid in boundary delineation. Map units are mostly consociations with few complexes and are phases of soil series or are miscellaneous areas. Some map units named at a categorical level above the series may be appropriate. Delineations have a minimum size of about 1 hectare (2.5 acres) or less, depending on scale, and contain a minimum amount of contrasting inclusions within the limits permitted by the kind of map unit used. Base map scale is generally 1:15,840 or larger.

Second-order surveys are made for intensive land uses that require detailed information about soil resources for making predictions of suitability for use and of treatment needs. The information can be used in planning for general agriculture, construction, urban development, and similar uses that require precise knowledge of the soils and their variability.

Field procedures permit plotting of soil boundaries by observation and by interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals, and the soils in each delineation are identified by traversing and in some map units by transecting. Map units are mostly consociations and complexes. Occasionally undifferentiated groups or associations are also used. Components of map units are phases of soil series or phases of miscellaneous areas; map units named at a categorical level above the series can be used. Delineations are variable in size with a minimum of 0.6 to 4 hectares (1.5 to 10 acres), depending on landscape complexity and survey objectives. Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:12,000 to 1:31,680, depending on the complexity of the soil pattern within the area.

Third-order surveys are made for land uses that do not require precise knowledge of small areas or detailed soils information. Such survey areas are usually dominated by a single land use and have few subordinate uses. The information can be used in planning for range, forest, recreational areas, and in community planning.

Field procedures permit plotting of most soil boundaries by observation and interpretation of remotely sensed data. Boundaries are verified by some field observations. The soils are identified by traversing representative areas and applying the information to like areas. Some additional observations and transects are made for verification. Map units include associations, complexes, consociations, and undifferentiated groups. Components of map units are phases of soil series, taxa above the

series, or they are miscellaneous areas. Delineations have a minimum size of about 1.6 to 16 hectares (4 to 40 acres), depending on the survey objectives and complexity of the landscapes. Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:20,000 to 1:63,360, depending on the complexity of the soil pattern and intended use of the maps.

Fourth-order surveys are made for extensive land uses that need general soil information for broad statements concerning land-use potential and general land management. The information can be used in locating, comparing, and selecting suitable areas for major kinds of land use, in regional land-use planning, and in selecting areas for more intensive study and investigation.

Field procedures permit plotting of soil boundaries by interpretation of remotely sensed data. The soils are identified by traversing representative areas to determine soil patterns and composition of map units and applying the information to like areas. Transects are made in selected delineations for verification. Most map units are associations, but some consociations and undifferentiated groups may be used in some surveys. Components of map units are phases of soil series, of taxa above the series, or are miscellaneous areas. Minimum size of delineations is at least 16 to 252 hectares (40 to 640 acres). Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:63,360 to 1:250,000.

Fifth-order surveys are made to collect soils information in very large areas at a level of detail suitable for planning regional land use and interpreting information at a high level of generalization. The primary use of this information is selection of areas for more intensive study.

Field procedures consist of mapping representative areas of 39 to 65 square kilometers (15 to 25 square miles) to determine soil patterns and composition of map units. This information is then applied to like areas by interpretation of remotely sensed data. Soils are identified by a few onsite observations or by traversing. Most map units are associations, but some consociations and undifferentiated groups may be used. Components of map units are phases of taxa at categorical levels above the series and miscellaneous areas. Minimum size of delineations is about 252 to 4,000 hectares (640 to 10,000 acres). Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base-map scale ranges from about 1:250,000 to 1:1,000,000 or smaller.

Two Orders of Soil Survey in the Same Project

Some soil survey areas have two or more separate and distinct parts that have different needs. For example, one part may be mapped to make pre-

dictions that pertain to irrigation, but the other may be mapped to make predictions that relate to range management. The irrigated part should be mapped at the intensity required for a second-order soil survey, and map units are mostly consociations of narrowly defined phases of soil series. The part used for grazing, however, can be mapped as a third-order survey and uses associations, complexes, and some consociations of more broadly defined phases of soil series or of taxa above the series. Some map units of the two parts will consist of the same kinds of soil, but great care is exercised to ensure that map units for the two different orders of soil survey maps do not have the same names or symbols.

Large, separate, and distinct areas that are within the same project but surveyed by different methods should be distinguished clearly by boundaries on the published soil map or on a small-scale inset map. Each part is identified by a note printed parallel to the line separating the areas of each survey order. The two parts have separate legends. The parts are considered as distinctly different orders of soil survey, but the results are reported in the same publication. The same or different map scales may be used for the different survey orders, depending on the intended uses.

Many 2nd-order surveys delineate some map units by methods that are less intensive, even though the areas mapped at different intensities are intermingled on the map. For example, within an otherwise detailed soil map, the delineations of very steep or very stony soils are commonly investigated at the intensity normally used in a third-order survey. This is discussed in soil survey procedures.

Still other soil surveys include areas consisting of two or more distinctive soils that could be mapped separately by detailed soil survey methods; however, the cost of making the separation cannot be justified. For example, a survey area that is mostly productive soils suitable for general farming may contain large areas of unproductive sandy soils covered with thick brush. Although the sandy areas contain contrasting kinds of soil that could be delineated separately, the cost of detailed mapping to separate the two kinds of soils may exceed the expected return. The outer boundaries of the sandy areas are plotted in as much detail and with as careful investigations as any other boundaries of the soil survey, but the sandy areas themselves are mapped by third- or fourth-order methods. Traverses are made, and the composition of the areas is defined in terms of the kinds, proportions, and patterns of the individual soils. The delineations are described in the text of the published soil survey as soil associations mapped by methods of the appropriate survey order.

Soil Maps Made by Other Methods

Although most soil maps published in the United States by the National Cooperative Soil Survey are made by field investigations, some are compiled from other sources. These kinds of soil maps are described in the following sections.

Generalized Soil Maps

Some users need soils information about areas larger than individual fields or tracts, as large as perhaps several square kilometers, but a detailed map tends to obscure the broad relationships. Generalized soil maps are made to reveal geographic relationships that cannot be seen readily on detailed maps. Most soil survey reports include a general soil map for the area. The scale of these maps depends on the intended uses.

Generalized soil maps are made by combining the delineations of existing soil survey maps to form broader map units. Scrutiny of a detailed map usually will find large areas in which a few soil series, commonly two or three, are consistently associated. A detailed map is generalized by enclosing those larger areas within which a few kinds of soil predominate in relatively consistent proportions and patterns. These larger areas are described in terms of the dominant soils. The map is interpreted to show the combined effects of the constituent soils of each map unit.

Some of the possible uses for generalized soil maps are for apprais-ing the basic soil resources of whole counties, for assisting farm advisors in the geographic emphasis of their educational programs, and for guid-ing commercial interests. Increasingly, these maps are compiled for county and regional land-use planning. Other possible uses include pre-dicting the general suitability of large areas of soils for residential, recre-ational, wildlife, and other nonfarm uses, as well as for agriculture. Suggesting alternative routes for roads and pipelines where the least problems with soils are expected is also a potential use. The information in generalized soil maps may be useful as one basis for zoning.

Soil maps that are already less detailed can be generalized further for purposes that require very broad perspective. For example, 4th-order soil surveys for individual counties at scales of less than 1:250,000 can be combined and generalized to provide maps of States or regions at a scale of 1:1,000,000 or smaller. Soil maps that show the soils of areas of a few square kilometers can be converted to maps having delineations of a few hundred square kilometers, or more. Areas defined as associations of soil series or their phases are combined in this process into larger areas that can be defined in terms of associations of taxa at higher categories. These broad soil associations can be divided into phases to specify

ranges in physiography, soil texture, or other features if such distinctions are useful. Soil maps at such levels of abstraction are designed for very broad regional planning and other uses that focus on areas of hundreds of square kilometers.

Schematic Soil Maps

Schematic soil maps are also compiled, but they differ from generalized soil maps in being compiled from information other than pre-existing soil maps. Scale is commonly 1:1,000,000 or smaller, although useful maps are sometimes made at larger scales. Schematic soil maps are commonly made as a preliminary step to locate areas where further investigation is justified. For many areas, especially in undeveloped regions, a schematic soil map is useful in advance of an organized field survey. Some maps serve as the only source of soils information in areas where more intensive studies are not feasible.

Schematic soil maps are made by using many sources of information to predict the geographic distribution of different kinds of soil. First, all available data are assembled. Information about climate, vegetation, geology, landforms, and other factors related to soil are gathered and studied. Data obtained by remote sensing techniques, including aerial photography, may provide useful information. Any available information about the soil is used to the extent justified by its quality. Some soils information exists for most parts of the world, but in wild areas the information may be mainly notes by travelers and rough maps interpreted from aerial photographs without verification on the ground.

Schematic soil maps merge with 5th-order (exploratory) soil surveys without a sharp line of distinction.

A soil is the unique result of five interrelated factors: *climate* and *living organisms*, conditioned by *relief (topography)*, acting on parent material for periods of time. If good geographic data about these factors are available, good soil maps can be compiled by experienced soil scientists who are familiar with the combinations of factors that produce the different kinds of soils. The amount of detail and verification by field investigation depends upon the purpose and intended use of the soil survey.

CHAPTER 3 Examination and Description of Soils

A description of the soils is essential in any soil survey. This chapter provides standards and guidelines for describing most soil properties and for describing the necessary related facts. For some soils, standard terms are not adequate and must be supplemented by a narrative. The length of time that cracks remain open, the patterns of soil temperature and moisture, and the variations in size, shape, and hardness of clods in the surface layer must be observed over time and summarized.

This chapter does not include a discussion of every possible soil property. For some soils, other properties need to be described. Good judgment will decide what properties merit attention in detail for any given pedon (sampling unit). Observations must not be limited by preconceived ideas about what is important.

Although the format of the description and the order in which individual properties are described are less important than the content of the description, a standard format has distinct advantages. The reader can find information more rapidly, and the writer is less likely to omit important features. Furthermore, a standard format makes it easier to code data for automatic processing. If forms are used, they must include space for all possible information. Formats for recording and retrieving information about pedons will be discussed in more detail in chapter 5.

Each investigation of the internal properties of a soil is made on a soil body of some dimensions. The body may be larger than a pedon or represent a portion of a pedon. During field operations, many soils are investigated by examining the soil material removed by a sampling tube or an auger. For rapid investigations of thin soils, a small pit can be dug and a section of soil removed with a spade. All of these are samples of pedons. Knowledge of the internal properties of a soil is derived mainly from studies of such samples. They can be studied more rapidly than entire pedons; consequently, a much larger number can be studied in many more places. For many soils, the information obtained from such a small sample describes the pedon from which it is taken with few omissions. For other soils, however, important properties of a pedon are not

observable in the smaller sample, and detailed studies of entire pedons may be needed. Complete study of an entire pedon requires the exposure of a vertical section and the removal of horizontal sections layer by layer. Horizons are studied in both horizontal and vertical dimensions.

Some General Terms Used in Describing Soils

Several of the general terms for internal elements of the soil are described here; other more specific terms are described or defined in the following sections.

A soil profile is exposed by a vertical cut through the soil. It is commonly conceived as a plane at right angles to the surface. In practice, a description of a soil profile includes soil properties that can be determined only by inspecting volumes of soil. A description of a pedon is commonly based on examination of a profile, and the properties of the pedon are projected from the properties of the profile. The width of a profile ranges from a few decimeters to several meters or more. It should be sufficient to include the largest structural units.

A soil horizon is a layer, approximately parallel to the surface of the soil, distinguishable from adjacent layers by a distinctive set of properties produced by the soil-forming processes. The term layer, rather than horizon, is used if all of the properties are believed to be inherited from the parent material or no judgment is made as to whether the layer is genetic.

The solum (plural, sola) of a soil consists of a set of horizons that are related through the same cycle of pedogenic processes. In terms of soil horizons described in this chapter, a solum consists of A, E, and B horizons and their transitional horizons and some O horizons. Included are horizons with an accumulation of carbonates or more soluble salts if they are either within, or contiguous, to other genetic horizons and are judged to be at least partly produced in the same period of soil formation. The solum of a soil presently at the surface, for example, includes all horizons now forming. It includes a bisequum (to be discussed). It does not include a buried soil or a layer unless it has acquired some of its properties by currently active soil-forming processes. The solum of a soil is not necessarily confined to the zone of major biological activity. Its genetic horizons may be expressed faintly to prominently. A solum does not have a maximum or a minimum thickness.

Solum and soils are not synonymous. Some soils include layers that are not affected by soil formation. These layers are not part of the solum. The number of genetic horizons ranges from one to many. An A horizon that is 10 cm thick overlying bedrock is by itself the solum. A soil that consists only of recently deposited alluvium or recently exposed soft sediment does not have a solum.[1]

In terms of soil horizons described in this chapter, a solum consists of A, E, and B horizons and their transitional horizons and some O horizons. Included are horizons with an accumulation of carbonates or more soluble salts if they are either within, or contiguous, to other genetic horizons and are judged to be at least partly produced in the same period of soil formation.

The lower limit, in a general sense, in many soils should be related to the depth of rooting to be expected for perennial plants assuming that water state and chemistry are not limiting. In some soils the lower limit of the solum can be set only arbitrarily and needs to be defined in relation to the particular soil. For example, horizons of carbonate accumulation are easily visualized as part of the solum in many soils in arid and semiarid environments. To conceive of hardened carbonate accumulations extending for 5 meters or more below the B horizon as part of the solum is more difficult. Gleyed soil material begins in some soils a few centimeters below the surface and continues practically unchanged to a depth of many meters. Gleying immediately below the A horizon is likely to be related to the processes of soil formation in the modern soil. At great depth, gleying is likely to be relict or related to processes that are more geological than pedological. Much the same kind of problem exists in some deeply weathered soils in which the deepest material penetrated by roots is very similar to the weathered material at much greater depth.

For some soils, digging deep enough to reveal all of the relationships between soils and plants is not practical. Roots of plants, for example, may derive much of their moisture from fractured bedrock close to the surface. Descriptions should indicate the nature of the soil-rock contact and as much as can be determined about the upper part of the underlying rock.

A <u>sequum</u> (plural, <u>sequa)</u> is a B horizon together with any overlying eluvial horizons. A single sequum is considered to be the product of a specific combination of soil-forming processes.

Most soils have a single sequum, but some have two or more. A Spodosol, for example, can form in the upper part of an Alfisol, producing an eluviated zone and a spodic horizon underlain by another eluviated zone overlying an argillic horizon. Such a soil has two sequa. Soils in which two sequa have formed, one above the other in the same deposit, are said to be <u>bisequal.</u>

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[1] As much as 50 cm of recently deposited sediment is disregarded in classifying the underlying set of genetic horizons (*Soil Taxonomy*). These thin deposits are not part of the solum but may be otherwise important. By the same convention, a soil is not considered to be buried (*Soil Taxonomy*) unless there is at least 50 cm of overlying sediment that has no genetic horizons in the lower part.

If two sequa formed in different deposits at different times, the soil is not bisequal. For example, a soil having an A-E-B horizon sequence may form in material that was deposited over another soil that already had an A-E-B horizon sequence. Each set of A-E-B horizons is a sequum but the combination is not a bisequum. The lower set is a buried soil. If the horizons of the upper sequum extend into the underlying sequum, the affected layer is considered part of the upper sequum. For example, the A horizon of the lower soil may retain some of its original characteristics and also have some characteristics of the overlying soil. Here, too, the soils are not considered bisequal; the upper part of the lower soil is the parent material of the lower part of the currently forming soil. In many soils the distinction cannot be made with certainty. Nevertheless, the distinction is useful when it can be made. Where some of the C material of the upper sequum remains, the distinction is clear.

Studying Pedons

Pedons representative of an extensive mappable area are generally more useful than pedons that represent the border of an area or a small inclusion.

For a soil description to be of greatest value, the part of the landscape that the pedon represents and the vegetation should be described. This is referred to as the setting. The level of detail will depend on the objectives. A complete setting description should include information about the encompassing polypedon and, possibly, the polypedons conterminous with the encompassing polypedon (Soil Survey Staff, 1975). Furthermore, the setting may include information about the portion of the polypedon that differs from the central concept of the polypedon.

The description of a body of soil in the field, whether an entire pedon or a sample within it, should record the kinds of layers, their depth and thickness, and the properties of each layer. Generally, external features are observed throughout the extent of the polypedon; internal features are observed from the study of a pedon or that part of a pedon that is judged to be representative of the polypedon (see appendix).

A pedon for detailed study of a soil is tentatively selected and then examined preliminarily to verify that it represents the desired segment of its range.

A pit exposing a vertical face approximately 1 meter across to an appropriate depth is satisfactory for most soils.[2]

[2] For soils having cyclic horizons or layers recurring at intervals between 2 m and 7 m, a pit large enough to study at least one half of the cycle is necessary.

After the sides of the pit are cleaned of all loose material disturbed by digging, the exposed vertical faces are examined, usually starting at the top and working downward, to identify significant changes in properties. Boundaries between layers are marked on the face of the pit, and the layers are identified and described.

Photographs should be taken (ch. 5) after the layers have been identified but before the vertical section is disturbed in the description-writing process. A point-count for estimation of the volume of stones or other features also is done before the layers are disturbed.

A horizontal view of each layer is useful. This exposes structural units that otherwise may not be observable. Patterns of color within structural units, variations of particle size from the outside to the inside of structural units, and the pattern in which roots penetrate structural units are often seen more clearly in a horizontal section.

Excavations associated with roads, railways, gravel pits, and other soil disturbances provide easy access for studying soils; old exposures, however, must be used cautiously. The soils dry out or freeze and thaw from both the surface and the sides. Frequently, the soil structure in such excavations is more pronounced than is typical; salts may accumulate near the edges of exposures or be removed by seepage; and other changes may have taken place.

Depth To and Thickness of Horizons and Layers

Depth is measured from the soil surface. The soil surface is the top of the mineral soil; or, for soils with an 0 horizon, the soil surface is the top of the part of the 0 horizon that is at least slightly decomposed. Fresh leaf or needle fall that has not undergone observable decomposition is excluded from soil and may be described separately. The top of any surface horizon identified as an O horizon, whether Oi, Oe, or Oa, is considered the soil surface.

For soils with a cover of 80 percent or more rock fragments on the surface, the depth is measured from the surface of the rock fragments.

The depth to a horizon or layer boundary commonly differs within short distances, even within a pedon. The part of the pedon that is typical or most common is described. In the soil description, the horizon or layer designation is listed and is followed by the values that represent the depths from the soil surface to the upper and lower boundaries, in that order. The depth to the lower boundary of a horizon or layer is the depth to the upper boundary of the horizon or layer beneath it. The variation in the depths of the boundaries is recorded in the description of the horizon or layer. The depth limits of the deepest horizon or layer described include only that part actually seen.

In some soils the variations in depths to boundaries are so complex that usual terms for description of topography of the boundary are inadequate. These variations are described separately. For example, "depth to the lower boundary is mainly 30 to 40 cm, but tongues extend to depths of 60 to 80 cm." The lower boundary of horizon or layer and the upper boundary of the horizon or layer below share a common irregularity.

The thickness of each horizon or layer is the vertical distance between the upper and lower boundaries. Thickness may vary within a pedon, and this variation should be shown in the description. A range in thickness may be given. It cannot be calculated from the range of upper and lower boundaries but rather must be evaluated across the exposure at different lateral points. The location of upper and lower boundaries are commonly in different places. The upper boundary of a horizon, for example, may range in depth from 25 to 45 cm and the lower boundary from 50 to 75 cm. Taking the extremes of these two ranges, a wrong conclusion could be that the horizon ranges in thickness from as little as 5 cm to as much as 50 cm.

Land Surface Configuration

Land surface configuration considered here is geometrical and includes <u>soil slope</u> and <u>land surface shape.</u> Landform from a morphogenetic aspect is not considered. It may be applicable to a pedon or to a larger area.

Land surface configuration and relief are quite different as used here, although the meanings may be similar in other contexts. <u>Relief,</u> in this context, refers to the elevation or differences in elevation above mean sea level, considered collectively, of a land surface on a broad scale. Elevation can be determined from topographic maps or by using a calibrated altimeter.

Soil Slope

<u>Slope</u> has a scale connotation. It refers to the ground surface configuration for scales that exceed about 10 meters and range upward to the landscape as a whole. Slope has gradient, complexity, length, and aspect. The scale of reference commonly exceeds that of the pedon and should be indicated. The scale may embrace a map unit delineation, component of it, or an arbitrary area.

<u>Slope gradient</u> is the inclination of the surface of the soil from the horizontal. It is generally measured with a hand level. The difference in elevation between two points is expressed as a percentage of the distance between those points. If the difference in elevation is 1 meter over a horizontal distance of 100 meters, slope gradient is 1 percent. A slope of 45° is a slope of 100 percent, because the difference in elevation between two points 100 meters apart horizontally is 100 meters on a 45° slope.

Overland flow gradient is the slope of the soil surface in the direction of flow of surface water if it were present. The following examples show equivalences between percentage gradient and degree of slope angle:

Percentage	Angle	Angle	Percentage
0	0°00′	0°	0
5	2°52′	2°	3.5
10	5°43′	4°	7.0
15	8°32′	6°	10.5
20	11°19′	8°	14.0
5	14°02′	10°	17.6
30	16°42′	12°	21.2
35	19°17′	15°	26.8
40	21°48′	20°	36.4
50	26°34′	25°	46.6
60	30°58′	30°	57.7
70	34°59′	35°	70.0
80	38°39′	40°	83.9
90	41°59′	45°	100.0
100	45°00′	50°	119.2

Slope Complexity refers to surface form on the scale of a mapping unit delineation. In many places internal soil properties are more closely related to the slope complexity than to the gradient. Slope complexity has an important influence on the amount and rate of runoff and on sedimentation associated with runoff.

A guide to terminology for various slope classes defined in terms of gradient and complexity is given in table 3-1. The terms are used in discussing soil slope, and they can also be used in naming slope phases, as discussed in the next chapter.

Terms are provided for both simple and for complex slopes in some classes. Complex slopes are groups of slopes that have definite breaks in several different directions and in most cases markedly different slope gradients within the areas delineated.

Significance of slope gradient is tied to other soil properties and to the purposes of soil surveys. Conventions are, therefore, provided in table 3-1 to adjust the slope limits of the various classes. Gently sloping or undulating soils, for example, can be defined to range as broadly as 1 to 8 percent or as narrowly as 3 to 5 percent. Classes may exceed the broadest range indicated in table 3-1 by a percentage point or two where the range is narrow and by as much as 5 percent or more where the range is broad.

TABLE 3-1

Definitions of Slope Classes

Classes: Simple slopes	Complex slopes	Slope gradient limits: Lower (Percent)	Upper (Percent)
Nearly level	Nearly level	0	3
Gently sloping	Undulating	1	8
Strongly sloping	Rolling	4	16
Moderately steep	Hilly	10	30
Steep	Steep	20	60
Very steep	Very steep	> 45	

If the detail of mapping requires slope classes that are more detailed than those in table 3-1, some of the classes can be divided as follows:

Nearly level:	Level, Nearly level
Gently sloping:	Very gently sloping, gently sloping
Strongly sloping:	Sloping, Strongly sloping, Moderately sloping
Undulating:	Gently undulating, Undulating
Rolling:	Rolling, Strongly rolling

In a highly detailed survey, for example, slope classes of 0 to 1 percent and 1 to 3 percent would be named "level" and "nearly level."

Slope length has considerable control over runoff and potential accelerated water erosion. Terms such as "long" or "short" can be used to describe slope lengths that are typical of certain kinds of soils. These terms are usually relative within a physiographic region. A "long" slope in one place might be "short" in another. If such terms are used, they are defined locally. For observations at a particular point, it may be useful to record the length of the slope that contributes water to the point in addition to the total length of the slope. The former is called point runoff slope length. The sediment transport slope length is the distance from the expected or observed initiation upslope of runoff to the highest local elevation where deposition of sediment would be expected to occur. This distance need not be the same as the point runoff slope length.

Slope aspect is the direction toward which the surface of the soil faces. The direction is expressed as an angle between 0 degree and 360 degrees (measured clockwise from true north) or as a compass point such as east or north-northwest. Slope aspect may affect soil temperature, evapotranspiration, and winds received.

Land Surface Shape

Land surface shape has two components (fig. 3-1). One component is in a direction roughly parallel to the contours of the landform (or the contour lines on a map) as seen from directly overhead. The other component of shape is a direction perpendicular to the contours; that is, the shape of the slope as seen from the side. The shape parallel to the contours is less commonly consistent for a soil than is the shape perpendicular to the contours.

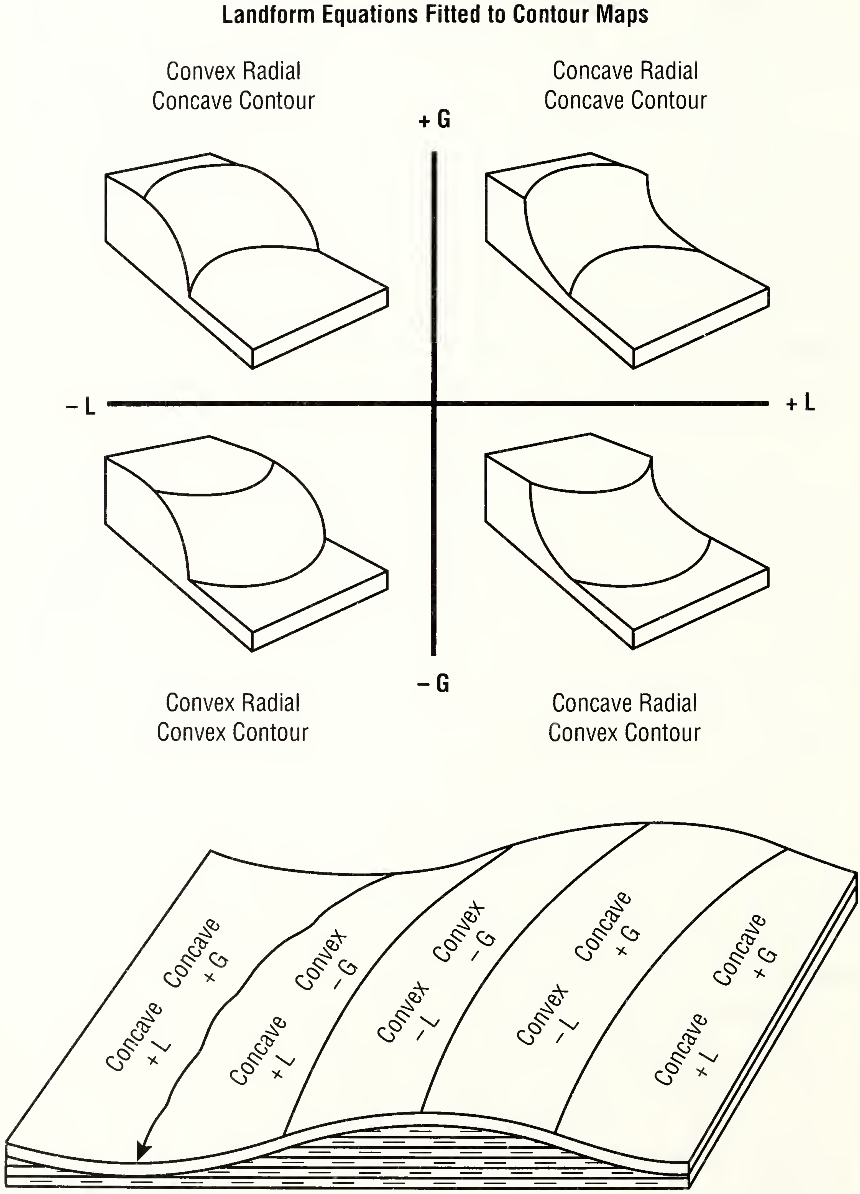
The shape parallel to the contours (across the slope) can be described by the shape of the contours. The shape is linear if contours are substantially a straight line, as on the side of a lateral moraine. An alluvial fan has a convex contour, as does a spur of the upland projecting into a valley. A cove on a hillside or a cirque in glaciated landscape have concave contours. In figure 3-1, the two upper blocks have concave contours and the two lower blocks have convex contours. Where the contour is convex, runoff water tends to spread laterally as it moves down the slope. Where the contour is concave, runoff water tends to be concentrated toward the middle of the landform.

The shape of the surface at right angles to the contours (up and down the slope) may also be described as linear, convex, or concave. Shape in this direction is usually identified simply as slope shape in contrast to slope contour in the other dimension. The surface of a linear slope is substantially a straight line when seen in profile at right angles to the contours. The gradient neither increases nor decreases significantly with distance. An example is the dip slope of a cuesta. On a concave slope (fig. 3-1, right), gradient decreases down the slope as on foot slopes. Runoff water tends to decelerate as it moves down the slope, and if it is loaded with sediment, the water tends to deposit the sediment on the lower parts of the slope. The soil on the lower part of the slope also tends to dispose of water less rapidly than the soil above it. On a convex slope (fig. 3-1, left), such as the shoulder or a ridge, gradient increases down the slope and runoff tends to accelerate as it flows down the slope. Soil on the lower part of the slope tends to dispose of water by runoff more rapidly than the soil above it. The soil on the lower part of a convex slope is subject to greater erosion than that on the higher part.

The configuration of the surface of a soil may be described in terms of both the shape of the contour and the shape of the slope. For example, a surface can be described as having a convex contour and a convex slope (an alluvial fan) or a linear contour and concave slope (the base of a moraine).

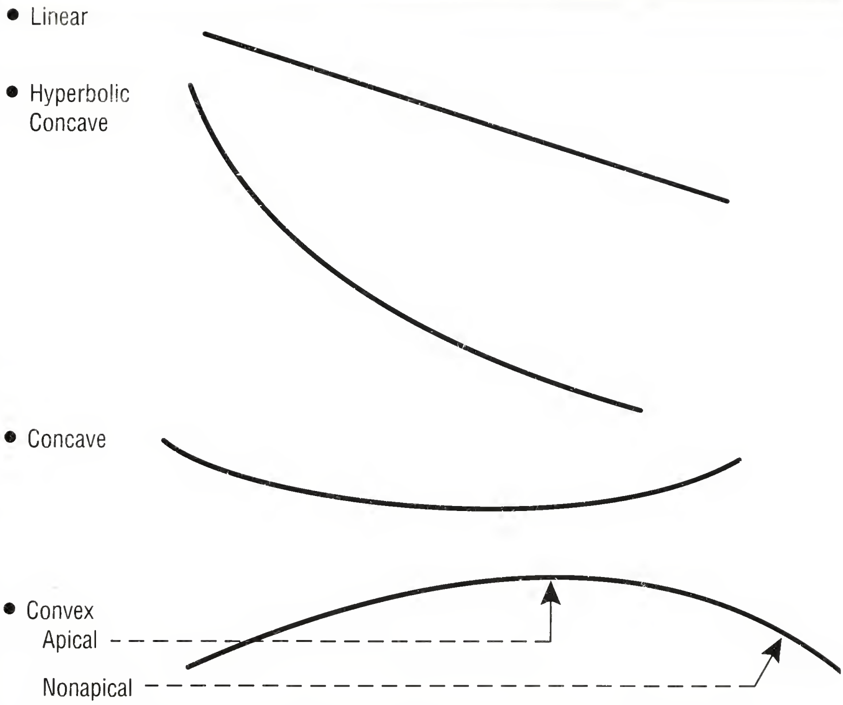
Description of an areal shape from the shape of two intersecting lines at right angles is applicable to all scales and does not require a contour map. The lines commonly would be parallel to and at right angles to the

FIGURE 3-1



Illustrations of four combinations of concavity and covexity.

FIGURE 3-2



Four shapes of lines for description of land surface shapes.

contour. Four line shapes are illustrated in figure 3-2: linear, hyperbolic concave (declining slope gradient along the line), concave, and convex. Convex site may be usefully separated into apical (summit) and nonapical (shoulder) positions.

Microrelief refers to differences in ground-surface height, measured over distances of meters. Naturally formed features contrast with those that are tillage-determined. In areas of similar relief, the surface may be nearly uniform, or it may be interrupted by mounds, swales, or pits. Examples include the microrelief created when trees are blown over, referred to as cradle-knoll microrelief. This consists of the knoll left by the earth that clung to the roots of the tree when it was uprooted and the depression from which it came. Coppice dunes form where windblown soil material accumulates around widely spaced plants in arid regions. Gilgai produced by expansion and contraction of soils is a form of microrelief (fig. 3-3). Mima mounds and biscuit-scabland are other examples of microrelief, although individual mounds may cover 100 square meters or more. Descriptions should indicate whether mounds or depres-

FIGURE 3-3

Characteristic microrelief of the gilgai type (Texas).

sions are closed, form a network, or are in a linear pattern. If mounds rest on a smooth surface, their size and spacing should be described. At a specific site within an area having microrelief, it is important to note whether a described pedon is at a high point, on a slope, in a depression, or at some combination of these places. Internal soil properties in mounds may be different from the properties in depressions.

Roughness refers to a ground surface configuration with a repeat distance between prominences of less than 50 cm and for areas less than about 10 m across. This scale applies to most tillage operations and affects aspects of land surface water flow such as detention, infiltration, runoff, and erosion. Roughness, as used here, pertains to the ground surface and includes rock fragments on the surface. It does not include vegetation. If vegetation is included, the fact should be indicated. Roughness along a line, referred to as one-dimensional roughness, can be measured more easily than can roughness for an area. Area measurements, however, permit the separation of random and tillage-determined roughness. The orientation to which the observation of one-dimensional roughness pertains must be specified relative to the direction of surface runoff or of air movement. Position within the tillage-determined relief, if present, should be indicated for one-dimensional roughness. An example of such a position would be the nontraffic interrow in a tilled field. The standard deviation of the ground surface height is the primary descriptor. There are a number of approaches to the measurement of roughness, and those who are

in agronomic disciplines should be consulted. The measurements depend on the variation in height from a leveled reference. Photographs may be used to illustrate the classes; placement in classes may be made directly from the photographs.

Vegetation

Correlations between vegetation and soils are made for three main purposes: (1) understanding soil genesis, (2) recognizing soil boundaries, and (3) making predictions from soil maps about the kind and amount of vegetation produced.

The principal kinds of plants present are listed in order of their abundance. In annual cropland, the plant or plants that have been grown should be recorded, including significant weeds. In forested areas, separate treatment is often necessary for forest trees, understory of small trees and shrubs, and the ground cover. Many soils in range have an overstory of shrubs or low trees. These are listed separately from the grasses, forbs, and other ground cover. An idea of the density of stand or plant cover, such as average canopy cover of trees or shrubs, should be given. The range in size of dominant species of trees can be given as "diameter breast height," if desired. Estimated percentage of the ground covered by grasses and forbs should be included.

Common names of the plants may be used, if such names are clear and specific. In areas where the plants are important for the use and interpretation of the soil map, the soil survey record should include both common and scientific names of plants.

If possible, the kinds and amounts of plants in the potential natural vegetation on a soil should be estimated. This vegetation is closely related to the soil and its genesis. Generally, a close relationship exists between native vegetation and kinds of soil, yet there are important exceptions. Observations of the growth of native vegetation and cultivated crops aid in recognizing soil boundaries and provide direct information about the behavior of specific plants on different kinds of soil. Within fields of a single crop, differences of vigor, stand, or color of the crop or of weeds commonly mark soil differences and are valuable clues to the location of soil boundaries.

By studying many sites of the same kind of soil under different land-use history, the potential plant community and principles of plant succession for that kind of soil can be ascertained, particularly if range and forestry specialists provide assistance. Farmers learn which crops do well and which do poorly on different kinds of soil and adjust their cropping patterns accordingly. If the differences are large—as between crop failure and reasonable performance—the near absence of a given crop on a spe-

cific kind of soil questions the suitability of that kind of soil for the crop. If the differences are small, many nonsoil factors can determine the farmer's choice of fields for a given crop. Yield information for cultivated crops, range, and trees should be associated with pedon descriptions insofar as possible.

Ground Surface Cover

The ground surface of most soils is covered to some extent at least part of the year by vegetation. Furthermore, in many soils rock fragments form part of the mineral material at the soil surface. Together, the vegetal material that is not part of the surface horizon and the rock fragments form the ground surface cover. The proportion of cover, together with its characteristics, is very important in determining thermal properties and resistance to erosion.

At one extreme, estimation of cover can be made visually without quantitative measurement. At the other extreme, transect techniques can be used to make a rather complete modal analyses of the ground surface. More effort is justified on ground surface documentation if it is relatively permanent. In many instances, a combination of rapid visual estimates and transect techniques is appropriate.

The ground surface may be divided into fine earth and material other than fine earth. The latter consists of rock fragments and both alive and dead vegetation. Vegetation is separated into <u>canopy</u> and <u>noncanopy.</u> A canopy component has a relatively large cross sectional area capable of intercepting rainfall compared to the area near enough to the ground surface to affect overland water flow. In practice, the separation of canopy from noncanopy should be coordinated with the protocols for computation of susceptibility to erosion. Noncanopy material is commonly referred to as <u>mulch.</u> It includes rock fragments and vegetation.

The first step in evaluation is to decide upon the ground surface cover components. The number is usually one to three. A common three-component land surface consists of trees, bushes, and areas between the two. The areal proportion of each component must be established. This may be done by transect. If a canopy component is present, the area within the drip line as a percent of the ground surface is determined. For each canopy component, the effectiveness must be established. <u>Effectiveness</u> is the percent of vertical raindrops that would be intercepted. Usually the canopy effectiveness is estimated visually, but a spherical densitometer may be used. In addition to the canopy effectiveness, the mulch (rock fragments plus vegetation) must be established for each component.

Transect techniques may be employed to determine the mulch percentage. The mulch can be subdivided into rock fragments and vegeta-

tion. From the areal proportions of the components and their respective canopy efficiencies and mulch percentages, the soil-loss ratio may be computed for the whole land surface (Wischmeier, 1978). In addition to the observations for the computation of the soil-loss ratio, information may be obtained about the percent of kinds of plants, size of rock fragments, amount of green leaf area, and aspects of color of the immediate surface that would affect absorption of radiant energy in an area.

Parent Material

Parent material refers to unconsolidated organic and mineral materials in which soils form. The parent material of a genetic horizon cannot be observed in its original state; it must be inferred from the properties that the horizon has inherited and from other evidence. In some soils, the parent material has changed little, and what it was like can be deduced with confidence. In others, such as some very old soils of the tropics, the specific kind of parent material or its mode or origin is speculative.

Much of the mineral matter in which soils form is derived in one way or another from hard rocks. Glaciers may grind the rock into fragments and earthy material and deposit the mixture of particles as glacial till. On the other hand, rock may be weathered with great chemical and physical changes but not moved from its place of origin; this altered material is called "residuum from rock."

In some cases, little is gained from attempting to differentiate between geologic weathering and soil formation because both are weathering processes. It may be possible to infer that a material was weathered before soil formation. The weathering process causes some process constituents to be lost, some to be transformed, and others to be concentrated.

Parent material may not necessarily be residuum from the bedrock that is directly below, and the material that developed into a modern soil may be unrelated to the underlying bedrock. Movement of soil material downslope is an important process and can be appreciable even on gentle slopes, especially on very old landscapes. Also, locally associated soils may form in sedimentary rock layers that are different.

Seldom is there certainty that a highly weathered material weathered in place. The term "residuum" is used when the properties of the soil indicate that it has been derived from rock like that which underlies it and when evidence is lacking that it has been modified by movement. A rock fragment distribution that decreases in amount with depth, especially over saprolite, indicates that soil material probably has been transported downslope. Stone lines, especially if the stones have a different lithology than the underlying bedrock, provide evidence that the soil did not form entirely in residuum. In some soils, transported material over-

lies residuum and illuvial organic matter and clay are superimposed across the discontinuity between the contrasting materials. A certain degree of landscape stability is inferred for residual soils. A lesser degree is inferred for soils that developed in transported material.

Both consolidated and unconsolidated material beneath the solum that influence the genesis and behavior of the soil are described in standard terms. Besides the observations themselves, the scientist records his judgment about the origin of the parent material from which the solum developed. The observations must be separated clearly from inferences.

The lithologic composition, structure and consistence of the material directly beneath the solum are important. Evidence of stratification of the material—textural differences, stone lines, and the like—need to be noted. Commonly, the upper layers of outwash deposits settled out of more slowly moving water and are finer in texture than the lower layers. Windblown material and volcanic ash are laid down at different rates in blankets of varying thickness. Examples of such complications are nearly endless.

Where alluvium, loess, or ash are rapidly deposited on old soils, buried soils may be well preserved. Elsewhere the accumulation is so slow that the solum thickens only gradually. In such places, the material beneath the solum was once near the surface but may now be buried below the zone of active change.

Where hard rocks or other strongly contrasting materials lie near enough to the surface to affect the behavior of the soil, their depths need to be measured accurately. The depth of soil over such nonconforming materials is an important criterion for distinguishing different kinds of soil.

Geological materials need to be defined in accordance with the accepted standards and nomenclature of geology. The accepted, authoritative names of the geological formations are recorded in soil descriptions where these can be identified with reasonable accuracy. As soil research progresses, an increasing number of correlations are being found between particular geological formations and the mineral and nutrient content of parent materials and soils. For example, certain terrace materials and deposits of volcanic ash that are different in age or source, but otherwise indistinguishable, vary widely in the content of cobalt. Wide variations in the phosphorus content of two otherwise similar soils may reflect differences in the phosphorus content of two similar limestones that can be distinguished in the field only by specific fossils.

Igneous rocks formed by the solidification of molten materials that originated within the earth. Examples of igneous rocks that weather to important soil material are granite, syenite, basalt, andesite, diabase, and rhyolite.

Sedimentary rocks formed from sediments laid down in previous geological ages. The principal broad groups of sedimentary rocks are limestone, sandstone, shale, and conglomerate. There are many varieties of these broad classes of sedimentary rocks; for example, chalk and marl are soft varieties of limestone. Many types are intermediate between the broad groups, such as calcareous sandstone and arenaceous limestone. Also included are deposits of diatomaceous earth, which formed, from the siliceous remains of primitive plants called diatoms.

Metamorphic rocks resulted from profound alteration of igneous and sedimentary rocks by heat and pressure. General classes of metamorphic rocks important as parent material are gneiss, schist, slate, marble, quartzite, and phyllite.

The principal broad subdivisions of parent material are discussed in the following paragraphs.

Material Produced by Weathering of Rock in Place

The nature of the original rock affects the kinds of material produced by weathering. The rock may have undergone various changes, including changes in volume and loss of minerals—plagioclase feldspar and other minerals. Rock may lose mineral material without any change in volume or in the original rock structure, and saprolite is formed. Essentially, saprolite is a parent material. The point where rock weathering ends and soil formation begins is not always clear. The processes may be consecutive and even overlapping. Quite different soils may form from similar or even identical rocks under different weathering conditions. Texture, color, consistence, and other characteristics of the material should be included in the description of soils, as well as important features such as quartz dikes. Useful information about the mineralogical composition, consistence, and structure of the parent rock itself should be added to help in understanding the changes from parent rock to weathered material.

Transported Material

The most extensive group of parent materials is the group that has been moved from the place of origin and deposited elsewhere. The principal groups of transported materials are usually named according to the main agent responsible for their transport and deposition. In most places, sufficient evidence is available to make a clear determination; elsewhere, the precise origin is uncertain.

In soil morphology and classification, it is exceedingly important that the characteristics of the material itself be observed and described. It is not enough simply to identify the parent material. Any doubt of the correctness of the identification should be mentioned. For example, it is

often impossible to be sure whether certain silty deposits are alluvium, loess, or residuum. Certain mud flows are indistinguishable from glacial till. Some sandy glacial till is nearly identical to sandy outwash. Fortunately, hard-to-make distinctions are not always of significance for soil behavior predictions.

Material moved and deposited by water

Alluvium.—Alluvium consists of sediment deposited by running water. It may occur on terraces well above present streams or in the normally flooded bottom land of existing streams. Remnants of very old stream terraces may be found in dissected country far from any present stream. Along many old established streams lie a whole series of alluvial deposits in terraces—young deposits in the immediate flood plain, up step by step to the very old deposits on the highest terraces. In some places recent alluvium covers older terraces.

Lacustrine deposits.—These deposits consist of material that has settled out of bodies of still water. Deposits laid down in fresh-water lakes associated directly with glaciers are commonly included as are other lake deposits, including some of Pleistocene age that are not associated with the continental glaciers. Some lake basins in the Western United States are commonly called playas; the soils in these basins may be more or less salty, depending on climate and drainage.

Marine sediments.—These sediments settled out of the sea and commonly were reworked by currents and tides. Later they were exposed either naturally or following the construction of dikes and drainage canals. They vary widely in composition. Some resemble lacustrine deposits.

Beach deposits.—Beach deposits mark the present or former shorelines of the sea or lakes. These deposits are low ridges of sorted material and are commonly sandy, gravelly, cobbly, or stony. Deposits on the beaches of former glacial lakes are usually included with glacial drift.

Material moved and deposited by wind

Windblown material can be divided into groups based on particle size or on origin. Volcanic ash and cinders are examples of materials classed by both particle size and origin. Other windblown material that is mainly silty is called loess, and that which is primarily sand is called eolian sand. Eolian sand is commonly but not always in dunes. Nearly all textures intermediate between silty loess and sandy dune material can be found.

Volcanic ash, pumice, and cinders are sometimes regarded as unconsolidated igneous rock, but they have been moved from their place of origin. Most have been reworked by wind and, in places, by water. Ash is

volcanic ejecta smaller than 2 mm. Ash smaller than 0.05 mm may be called "fine ash." Pumice and cinders are volcanic ejecta 2 mm or larger.

Loess deposits typically are very silty but may contain significant amounts of clay and very fine sand. Most loess deposits are pale brown to brown, although gray and red colors are common. The thick deposits are generally massive and have some gross vertical cracking. The walls of road cuts in thick loess stand nearly vertical for years. Other silty deposits that formed in other ways have some or all of these characteristics. Some windblown silt has been leached and strongly weathered so that it is acid and rich in clay. On the other hand, some young deposits of windblown material (loess) are mainly silt and very fine sand and are low in clay.

Sand dunes, particularly in warm, humid regions, characteristically consist of fine or medium sand that is high in quartz and low in clay-forming materials. Sand dunes may contain large amounts of calcium carbonate or gypsum, especially in deserts and semideserts.

During periods of drought and in deserts, local wind movements may mix and pile up soil material of different textures or even material that is very rich in clay. Piles of such material have been called "soil dunes" or "clay dunes." Rather than identify local accumulations of mixed material moved by the wind as "loess" or "dunes," however, it is better to refer to them as "wind-deposited material."

Also important but not generally recognized as a distinctive deposit is dust, which is carried for long distances and deposited in small increments on a large part of the world. Dust can circle the earth in the upper atmosphere. Dust particles are mostly clay and very fine silt and may be deposited dry or be in precipitation. The accumulated deposits are large in some places. An immense amount of dust has been distributed widely throughout the ages. The most likely sources at present are the drier regions of the world. Large amounts of dust may have been distributed worldwide during and immediately following the glacial periods.

Dust is an important factor affecting soils in some places. It is the apparent source of the unexpected fertility of some old, highly leached soils in the path of wind that blows from extensive deserts some hundreds of kilometers distant. It explains unexpected micronutrient distribution in some places. Besides dust, fixed nitrogen, sulfur, calcium, magnesium, sodium, potassium, and other elements from the atmosphere are deposited on the soil in varying amounts in solution in precipitation.

Material moved and deposited by glacial processes

Several terms are used for material that has been moved and deposited by glacial processes. Glacial drift consists of all of the material picked up, mixed, disintegrated, transported, and deposited by glacial ice or by

water from melting glaciers. In many places glacial drift is covered by a mantle of loess. Deep mantles of loess are usually easily recognized, but very thin mantles may be so altered by soil-building forces that they can scarcely be differentiated from the underlying modified drift.

Glacial till.—This is that part of the glacial drift deposited directly by the ice with little or no transportation by water. It is generally an unstratified, heterogeneous mixture of clay, silt, sand, gravel, and sometimes boulders. Some of the mixture settled out as the ice melted with very little washing by water, and some was overridden by the glacier and is compacted and unsorted. Till may be found in ground moraines, terminal moraines, medial moraines, and lateral moraines. In many places it is important to differentiate between the tills of the several glaciations. Commonly, the tills underlie one another and may be separated by other deposits or old, weathered surfaces. Many deposits of glacial till were later eroded by the wave action in glacial lakes. The upper part of such wave-cut till may have a high percentage of rock fragments.

Glacial till ranges widely in texture, chemical composition, and the degree of weathering that followed its deposition. Much till is calcareous, but an important part is noncalcareous because no carbonate rocks contributed to the material or because subsequent leaching and chemical weathering have removed the carbonates.

Glaciofluvial deposits.—These deposits are material produced by glaciers and carried, sorted, and deposited by water that originated mainly from melting glacial ice. <u>Glacial</u> <u>outwash</u> is a broad term for material swept out, sorted, and deposited beyond the glacial ice front by streams of melt water. Commonly, this outwash is in the form of plains, valley trains, or deltas in old glacial lakes. The valley trains of outwash may extend far beyond the farthest advance of the ice. Near moraines, poorly sorted glaciofluvial material may form kames, eskers, and crevasse fills.

Glacial beach deposits.—These consist of rock fragments and sand. They mark the beach lines of former glacial lakes. Depending on the character of the original drift, beach deposits may be sandy, gravelly, cobbly, or stony.

Glaciolacustrine deposits.—These deposits are derived from glaciers but were reworked and laid down in glacial lakes. They range from fine clay to sand. Many of them are stratified or varved. A <u>varve</u> consists of the deposition for a calendar year. The finer portion reflects slower deposition during the cold season and the coarser portion deposition during the warmer season when runoff is greater.

Good examples of all of the glacial materials and forms described in the preceding paragraphs can be found. In many places, however, it is not easy to distinguish definitely among the kinds of drift on the basis of mode of origin and landform. For example, pitted outwash plains can

scarcely be distinguished from sandy till in terminal moraines. Distinguishing between wave-cut till and lacustrine material is often difficult. The names themselves connote only a little about the actual characteristics of the parent material.

Material moved and deposited by gravity

Colluvium is poorly sorted debris that has accumulated at the base of slopes, in depressions, or along small streams through gravity, soil creep, and local wash. It consists largely of material that has rolled, slid or fallen down the slope under the influence of gravity. Accumulations of rock fragments are called talus. The rock fragments in colluvium are usually angular, in contrast to the rounded, water-worn cobbles and stones in alluvium and glacial outwash.

Organic Material

Organic material accumulates in wet places where it is deposited more rapidly than it decomposes. These deposits are called peat. This peat in turn may become parent material for soils. The principal general kinds of peat, according to origin are:

Sedimentary peat. the remains mostly of floating aquatic plants, such as algae, and the remains and fecal material of aquatic animals, including coprogenous earth.

Moss peat. the remains of mosses, including Sphagnum.

Herbaceous peat. the remains of sedges, reeds, cattails, and other herbaceous plants.

Woody peat. the remains of trees, shrubs, and other woody plants.

Many deposits of organic material are mixtures of peat. Some organic soils formed in alternating layers of different kinds of peat. In places peat is mixed with deposits of mineral alluvium and/or volcanic ash. Some organic soils contain layers that are largely or entirely mineral material.

In describing organic soils, the material is called peat (fibric) if virtually all of the organic remains are sufficiently fresh and intact to permit identification of plant forms. It is called muck (sapric) if virtually all of the material has undergone sufficient decomposition to limit recognition of the plant parts. It is called mucky peat (hemic) if a significant part of the material can be recognized and a significant part cannot.

Descriptions of organic material should include the origin and the

botanical composition of the material to the extent that these can be reasonably inferred.

Contrasting Materials

Changes with depth that are not primarily related to pedogenesis but rather to geological processes are contrasting soil materials if they are sufficient to affect use and management. The term discontinuity is applied to certain kinds of contrasting soil materials.

Unconsolidated contrasting soil material may differ in pore-size distribution, particle-size distribution, mineralogy, bulk density, or other properties. Some of the differences may not be readily observable in the field. Some deposits are clearly stratified, such as some lake sediments and glacial outwash, and the discontinuities may be sharply defined.

Contrasting materials can be confused with the effects of soil formation. Silt content may decrease regularly with depth in soils presumed to have formed in glacial till. The higher silt content in the upper part of these soils can be explained by factors other than soil formation. In some of these soils, small amounts of eolian material may have been deposited on the surface over the centuries and mixed by insects and rodents with the underlying glacial till. In others, the silt distribution reflects water sorting.

Inferences about contrasting properties inherited from differing layers of geologic material may be noted when the soil is described. Generally, each identifiable layer that differs clearly in properties from adjacent layers is recognized as a subhorizon. Whether it is recognized as a discontinuity or not depends on the degree of contrast with overlying and underlying layers and the thickness. For many soils the properties inherited from even sharply contrasting layers are not consistent from place to place and are described in general terms. The C layer of a soil in stratified lake sediments, for example, might be described as follows: "consists of layers of silt and clay, 1 to 20 cm thick; the aggregate thickness of layers of silt and that of the layers of clay are in a ratio of about 4 to 1; material is about 80 percent silt."

Erosion

Erosion is the detachment and movement of soil material. The process may be natural or accelerated by human activity. Depending on the local landscape and weather conditions, erosion may be very slow or very rapid.

Natural erosion has sculptured landforms on the uplands and built landforms on the lowlands. Its rate and distribution in time controls the age of land surfaces and many of the internal properties of soils on the

surfaces. The formation of Channel Scablands in the state of Washington is an example of extremely rapid natural, or geologic, erosion. The broad, nearly level interstream divides on the Coastal Plain of the Southeastern United States are examples of areas with very slow or no natural erosion.

Landscapes and their soils are evaluated from the perspective of their natural erosional history. Buried soils, stone lines, deposits of wind-blown material, and other evidence that material has been moved and redeposited is helpful in understanding natural erosion history. Thick weathered zones that developed under earlier climatic conditions may have been exposed to become the material in which new soils formed. In landscapes of the most recently glaciated areas, the consequences of natural erosion, or lack of it, are less obvious than where the surface and the landscape are of an early Pleistocene or even Tertiary age. Even on the landscapes of most recent glaciation, however, postglacial natural erosion may have redistributed soil materials on the local landscape. Natural erosion is an important process that affects soil formation and, like man-induced erosion, may remove all or part of soils formed in the natural landscape.

Accelerated erosion is largely the consequence of human activity. The primary causes are tillage, grazing, and cutting of timber.

The rate of erosion can be increased by activities other than those of humans. Fire that destroys vegetation and triggers erosion has the same effect. The spectacular episodes of erosion, such as the soil blowing on the Great Plains of the Central United States in the 1930's, have not all been due to human habitation. Frequent dust storms were recorded on the Great Plains before the region became a grain-producing area. "Natural" erosion is not easily distinguished from "accelerated" erosion on every soil. A distinction can be made by studying and understanding the sequence of sediments and surfaces on the local landscape, as well as by studying soil properties.

Landslip Erosion

Landslip erosion refers to the mass movement of soil. Slides and flows are two kinds of landslip erosion. In the slide process, shear takes place along one or a limited number of surfaces. Slide movement may be categorized as slightly or highly deformed, depending on the extent of rearrangement from the original organization. In flow movement the soil mass acts as a viscous fluid. Failure is not restricted to a surface or a small set of surfaces. Classes of landslip erosion are not provided. Location of the mass movement relevant to landscape features generally and the size of the mass movement in terms of area parallel to the land surface and the depth may be indicated. Information about the time since the mass movement took place may be very useful.

Water Erosion

Water erosion results from the removal of soil material by flowing water. A part of the process is the detachment of soil material by the impact of raindrops. The soil material is suspended in runoff water and carried away. Four kinds of accelerated water erosion are commonly recognized: sheet, rill, gully, and tunnel (piping).

> Sheet erosion is the more or less uniform removal of soil from an area without the development of conspicuous water channels. The channels are tiny or tortuous, exceedingly numerous, and unstable; they enlarge and straighten as the volume of runoff increases. Sheet erosion is less apparent, particularly in its early stages, than other types of erosion. It can be serious on soils that have a slope gradient of only 1 or 2 percent; however, it is generally more serious as slope gradient increases.

> Rill erosion is the removal of soil through the cutting of many small, but conspicuous, channels where runoff concentrates. Rill erosion is intermediate between sheet and gully erosion. The channels are shallow enough that they are easily obliterated by tillage; thus, after an eroded field has been cultivated, determining whether the soil losses resulted from sheet or rill erosion is generally impossible.

> Gully erosion is the consequence of water that cuts down into the soil along the line of flow. Gullies form in exposed natural drainageways, in plow furrows, in animal trails, in vehicle ruts, between rows of crop plants, and below broken man-made terraces. In contrast to rills, they cannot be obliterated by ordinary tillage. Deep gullies cannot be crossed with common types of farm equipment.

Gullies and gully patterns vary widely. V-shaped gullies form in material that is equally or increasingly resistant to erosion with depth (fig. 3-4). U-shaped gullies form in material that is equally or decreasingly resistant to erosion with depth (fig. 3-5). As the substratum is washed away, the overlying material loses its support and falls into the gully to be washed away. Most-U-shaped gullies become modified toward a V shape once the channel stabilizes and the banks start to spall and slump.

The maximum depth to which gullies are cut is governed by resistant layers in the soil, by bedrock, or by the local base level. Many gullies develop headward; that is, they extend up the slope as the gully deepens in the lower part.

FIGURE 3-4

V-shaped gullies in a material relatively high in clay.

Tunnel erosion may occur in soils with subsurface horizons or layers that are more subject to entrainment in moving free water than is the surface horizon or layer. The free water enters the soil through ponded infiltration into surface-connected macropores. Desiccation cracks and rodent burrows are examples of macropores that may initiate the process. The soil material entrained in the moving water moves downward within the soil and may move out of the soil completely if there is an outlet. The result is the formation of tunnels (also referred to as pipes) which enlarge and coalesce. The portion of the tunnel near the inlet may enlarge disproportionately to form a funnel-shaped feature often referred to as a "jug." Hence, the term "piping" and "jugging." The phenomenon is favored by the presence of appreciable exchangeable sodium.

Deposition of sediment carried by water is likely anywhere that the velocity of running water is reduced—at the mouth of gullies, at the base of slopes, along stream banks, on alluvial plains, in reservoirs, and at the

FIGURE 3-5

U-shaped gullies in a soil underlain by more erodible material.

mouth of streams. Rapidly moving water, when slowed, drops stones, then cobbles, pebbles, sand, and finally silt and clay. Sediment transport slope length has been defined as the distance from the highest point on the slope where runoff may start to where the sediment in the runoff would be deposited.

Wind Erosion[3]

Wind Erosion in regions of low rainfall, can be widespread, especially during periods of drought. Unlike water erosion, wind erosion is generally not related to slope gradient. The hazard of wind erosion is increased by removing or reducing the vegetation.

When winds are strong, coarser particles are rolled or swept along on or near the soil surface, kicking finer particles into the air. The particles are deposited in places sheltered from the wind. When wind erosion is severe, the sand particles may drift back and forth locally with changes

[3]"Wind Erosion" is sometimes used for the sculpture of rocks by wind-blown particles. The term is used in this manual, in soil science generally, and by many geologists for the detachment, transportation, and deposition of soil particles by wind.

in wind direction while the silt and clay are carried away. Small areas from which the surface layer has blown away may be associated with areas of deposition in such an intricate pattern that the two cannot be identified separately on soil maps.

Estimating the Degree of Erosion

The degree to which accelerated erosion has modified the soil may be estimated during soil examinations. The conditions of eroded soil are based on a comparison of the suitability for use and the management needs of the eroded soil with those of the uneroded soil. The eroded soil is identified and classified on the basis of the properties of the soil that remains. An estimate of the soil lost is described. Eroded soils are defined so that the boundaries on the soil maps separate soil areas of unlike use suitabilities and unlike management needs.

The depth to a reference horizon or soil characteristic of the soil under a use that has minimized accelerated erosion are compared to the same properties under uses that have favored accelerated erosion. For example, a soil that supports native grass or large trees with no evidence of cultivation would be the basis for comparison of the same or similar soil that has been cleared and cultivated for a relatively long time. The depth to reference layers is measured from the top of the mineral soil because organic horizons at the surface of mineral soils are destroyed by cultivation.

The depths to a reference layer must be interpreted in terms of recent soil use or history. Cultivation may cause differences in thickness of layers. The upper parts of many forested soils have roots that make up as much as one-half of the soil volume. When these roots decay, the soil settles. Rock fragment removal can also lower the surface. The thickness of surficial zones that have been bulked by tillage should be adjusted downward to what they would be if water had compacted them.

The thickness of a plowed layer of a specific soil cannot be used as a standard for either losses or additions of material because, as a soil erodes, the plow cuts progressively deeper. Nor can the thickness of the uncultivated and uneroded A horizon be used as a standard for all cultivated soil, unless the A horizon is much thicker than the plow layer. If the horizon immediately below the plowed layer of an uneroded soil is distinctly higher in clay than the A horizon, the plow layer becomes progressively more clayey under continued cultivation as erosion progresses; the texture of the plow layer may then be a criterion of erosion.

Comparisons must be made on comparable slopes. Near the upper limit of the range of slope gradient for a soil, horizons may normally be thinner than near the lower limit of the range for the same soil.

Roadsides, cemeteries, fence rows, and similar uncultivated areas that are a small part of the landscape as a whole or are subject to unusual cultural histories must be used cautiously for setting standards, because the reference standards for surface-layer thickness are generally set too high. In naturally treeless areas or in areas cleared of trees, dust may collect in fence rows, along roadsides, and in other small uncultivated areas that are covered with grass or other stabilizing plants. The dust thus accumulated may cause the surface horizon to become several centimeters thicker in a short time.

For soils having clearly defined horizons, differences due to erosion can be accurately determined by comparison of the undisturbed or uncultivated norms within the limitations discussed. Guides for soils having a thin A horizon and little or no other horizon are more difficult to establish. After the thin surface layer is gone or has been mixed with underlying material, few clues remain for estimating the degree of erosion. The physical conditions of the material in the plowed layer, the appearance and amount of rock fragments on the surface, the number and shape of gullies, and similar evidence are relied on. For many soils having almost no horizon expression, attempting to estimate the degree of erosion serves little useful purpose.

Classes of Accelerated Erosion

The classes of accelerated erosion that follow apply to both water and wind erosion. They are not applicable to landslip or tunnel erosion. The classes pertain to the proportion of upper horizons that have been removed. These horizons may range widely in thickness; therefore, the absolute amount of erosion is not specified.

> **Class 1.** This class consists of soils that have lost some, but on the average less than 25 percent, of the original A and/or E horizons or of the uppermost 20 cm if the original A and/or E horizons were less than 20 cm thick. Throughout most of the area, the thickness of the surface layer is within the normal range of variability of the uneroded soil. Scattered small areas amounting to less than 20 percent of the area may be modified appreciably.

Evidence for class 1 erosion includes (1) a few rills, (2) an accumulation of sediment at the base of slopes or in depressions, (3) scattered small areas where the plow layer contains material from below, and (4) evidence of the formation of widely spaced, deep rills or shallow gullies without consistently measurable reduction in thickness or other change in properties between the rills or gullies. Figure 3-6 is an example of class 1 erosion.

FIGURE 3-6

Sheet erosion. Rills formed as water accumulated in small channels part way down the slope. Sediment was deposited at the foot of the slope.

Class 2. This class consists of soils that have lost, on the average, 25 to 75 percent of the original A and/or E horizons or of the uppermost 20 cm if the original A and/or E horizons were less than 20 cm thick. Throughout most cultivated areas of class 2 erosion, the surface layer consists of a mixture of the original A and/or E horizons and material from below. Some areas may have intricate patterns, ranging from uneroded small areas to severely eroded small areas. Where the original A and/or E horizons were very thick, little or no mixing of underlying material may have taken place. Figure 3-7 is an example of class 2 erosion.

Class 3. This class consists of soils that have lost, on the average, 75 percent or more of the original A and/or E horizons or of the uppermost 20 cm if the original A and/or E horizons were less than 20 cm thick. In most areas of class 3 erosion, material below the original A and/or E horizons is exposed at the surface in cultivated areas; the plow layer consists entirely or largely of this material. Even where the original A and/or E horizons were very thick, at least some mixing with underlying material generally took place. Figure 3-8 is an example of class 3 erosion.

FIGURE 3-7

Class 2 erosion. The plowed layer of the light-colored areas is made up mainly of the original surface soil, whereas the plowed layer of the dark-colored areas is a mixture of the original surface soil and an underlying horizon.

FIGURE 3-8

Class 3 erosion. Gullies at the left require a gully symbol. The rills would be obliterated by tillage. Most of the original surface soil between rills has been lost.

Class 4. This class consists of soils that have lost all of the original A and/or E horizons or the uppermost 20 cm if the original A and/or E horizons were less than 20 cm thick. In addition, Class 4 includes some or all of the deeper horizons throughout most of the area. The original soil can be identified only in small areas. Some areas may be smooth, but most have an intricate pattern of gullies. Figure 3-9 is an example of class 4 erosion.

Soil Water

This section discusses "the water regime"—schemes for the description of the state of the soil water at a particular time and for the change in soil water state over time. Soil water state is evaluated from water suction, quantity of water, whether the soil water is liquid or frozen, and the occurrence of free water within the soil and on the land surface. Complexity and detail of water regime statements may range widely.

Inundation Classes

Free water may occur above the soil. Inundation is the condition that the soil area is covered by liquid free water. Flooding is temporary inundation by flowing water. If the water is standing, as in a closed depression, the term ponding is used.

FIGURE 3-9

Class 4 erosion intermingled with class 3 erosion. The areas in the middle and left have lost almost all diagnostic horizons. The areas in the foreground and far background have class 3 erosion.

Internal Classes

Definitions.—Table 3-2 contains water state classes for the description of individual layers or horizons. Only matrix suction is considered in definition of the classes.[4] Osmotic potential is not considered. For water contents of medium and fine-textured soil materials at suctions less than about 200 kPa, the reference laboratory water retention is for the natural soil fabric. Class limits are expressed both in terms of suction and water content. In order to make field and field office evaluation more practicable, water content pertains to gravimetric quantities and not to volumetric. The classes are applicable to organic as well as to mineral soil material. The frozen condition is indicated separately by the symbol "f." The symbol indicates the presence of ice; some of the water may not be frozen. If the soil is frozen, the water content or suction pertains to what it would be if not frozen.

Three classes and eight subclasses are defined. Classes and subclasses may be combined as desired. Symbols for the combinations currently defined are in table 3-2. Specificity desired and characteristics of the water desorption curve would determine whether classes or subclasses would be used. Coarse soil material has little water below the 1500 kPa retention, and so subdivisions of dry generally would be less useful.

Dry is separated from *moist* at 1500 kPa suction. *Wet* is separated from moist at the condition where water films are readily apparent. The water suction at the moist-wet boundary is assumed to be about 1/2 kPa for coarse soil materials and 1 kPa for other materials. The formal definition of coarse soil material is given later.

Three subclasses of dry are defined—*very dry*, *moderately dry*, and *slightly dry*. Very dry cannot be readily distinguished from air dry in the field. The water content extends from ovendry to 0.35 times the water retention at 1500 kPa. The upper limit is roughly 150 percent of the air dry water content. The limit between moderately dry and slightly dry is a water content 0.8 times the retention at 1500 kPa.

The moist class is subdivided into *slightly moist*, *moderately moist*, and *very moist*. Depending on the kind of soil material, laboratory retention at 5 or 10 kPa suction (method 4B, Soil Survey Laboratory Staff, 1992) determines the *upper water retention*. A suction of 5 kPa is employed for coarse soil material. Otherwise, 10 kPa is used.

> To be considered coarse, the soil material that is strongly influenced by volcanic ejecta must be nonmedial and weakly or nonvesicular. If not strongly influenced by volcanic ejecta, it must meet the sandy or sandy-skeletal family particle size criteria and also be coarser than

TABLE 3-2.

Water State Classes

Class	Criteria *a*
Dry (D)	>1500 kPa suction
Very Dry (DV)	<(.35 x 1500 kPa retention)
Moderately Dry (DM)	.35-.8 x 1500 kPa retention
Slightly Dry (DS)	0.8-1.0 x 1500 kPa retention
Moist (M)	<1500 kPa to >1 or 1/2 kPa *b*
Slightly Moist (MS)	1500 kPa suction to MWR *c*
Moderately Moist (MM)	MWR to UWR *c*
Very Moist (MV)	UWR to 1 or 1/2 kPa *b* suction
Wet (W)	<1 kPa or <1/2 kPa *b*
Nonsatiated (WN)	No free water
Satiated (WA)	Free water present

a Criteria use both suction and gravimetric water contents as defined by suction.

b 1/2 kPa only if coarse soil material (see text).

c UWR is the abbreviation for upper water retention, which is the laboratory water retention at 5 kPa for coarse soil material and 10 kPa for other (see text). MWR is the midpoint water retention. It is halfway between the upper water retention and the retention at 1500 kPa.

loamy fine sand, have <2 percent organic carbon, and have <5 percent water at 1500 kPa suction. Furthermore, the computed total porosity of the <2 mm fabric must exceed 35 percent.[5]

[4]The primary unit for suction is the pascal (symbol, Pa). The kilopascal (symbol kPa) is commonly employed. A kilopascal is 1000x a pascal. One bar is 100 kilopascals.

[5]
$$\text{Total porosity} = 100 - \left(\frac{Db}{Dp} \times 100\right)$$

where Db is the bulk density of the <2mm material at or near field capacity and Dp is the particle density. The particle density may be computed from the following:

(Footnote continued on next page)

Very moist has an upper limit at the moist-wet boundary and a lower limit at the upper water retention. Relatedly, *moderately moist* has an upper limit at the upper water retention and a lower limit at the midpoint in gravimetric water content between retention at 1500 kPa and the upper water retention. This lower limit is referred to as the midpoint water retention. *Slightly moist*, in turn, extends from the midpoint water retention to the 1500 kPa retention.

The wet class has *nonsatiated* and *satiated* subclasses distinguished on the basis of absence or presence of free water. Miller and Bresler (1977) defined satiation as the condition from the first appearance of free water through saturation. The nonsatiated wet state may be applicable at zero suction to horizons with low or very low saturated hydraulic conductivity. These horizons may not exhibit free water. Horizons may have parts that are *satiated wet* and other parts, because of low matrix saturated hydraulic conductivity and the absence of conducting macroscopic pores, that are *nonsatiated wet*. Free water develops positive pressure with depth below the top of a wet satiated zone.

A class for saturation (that is, zero air-filled porosity) is not provided because the term suggests that all of the pore space is filled with water. This condition usually cannot be evaluated in the field. Further, if saturation is used for the concept of satiation, then a term is not available to describe known saturation. There is an implication of saturation if the soil material is satiated wet and coarse-textured or otherwise has properties indicative of high or very high saturated hydraulic conductivity throughout the mass. A satiated condition does not necessarily indicate reducing conditions. Air may be present in the water and/or the microbiological activity may be low. The presence of reducing conditions may be inferred from soil color in some instances and a test may be performed for ferrous iron in solution. The results of the test for ferrous iron should be reported separately from the water-state description.

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[5](Footnote continued from previous page)

$$Dp = \frac{100}{\dfrac{(1.7 \times OC)}{Dp1} + \dfrac{(1.6 \times Fe)}{Dp2} + \dfrac{100 - [(1.7 \times OC) + (1.6 \times Fe)]}{Dp3}}$$

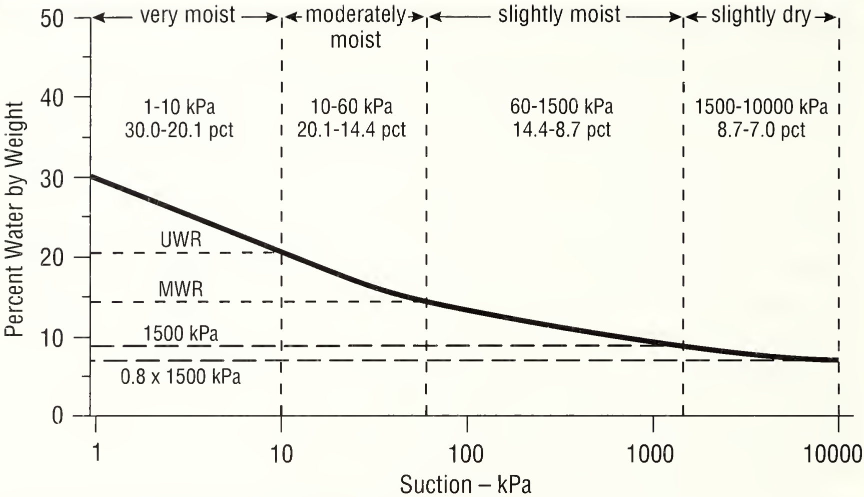
where OC is the organic carbon percentage and Fe is the extractable iron by method 6C2 (Soil Survey Laboratory Staff, 1992) or an equivalent method. The particle density of the organic matter (Dp1) is assumed to be 1.4 Mg/m^3, that of the minerals from which the extractable iron originates (Dp2) to be 4.2 Mg/m^3, and the material exclusive of the organic matter and the minerals contributing to the extractable Fe (Dp3) to be 2.65 Mg/m^3.

Evaluation.—*Wet* is indicated by the occurrence of prominent water films on surfaces of sand grains and structural units that cause the soil material to glisten. If free water is absent, the term *nonsatiated wet* is used. If free water is present, the term *satiated wet* is used. The position of the upper field boundary of the satiated wet class, in a formal sense, is the top of the water in an unlined bore hole after equilibrium has been reached. Determination of the thickness of a perched zone of free water requires the installation of lined bore holes or piezometers to several depths across the zone of free water occurrence. Piezometers are tubes placed to the designated depth that are open at both ends, may have a perforated zone at the bottom, but do not permit water entry along most of their length. In the context here, information about the depth of free water and location and thickness of the free water zone would be obtained in the course of soil examination for a range of purposes and does not necessarily require installation of bore holes.

Ideally, evaluation within the moist and dry classes should be based on field instrumentation. Usually, such instrumentation is not available and approximations must be made. Gravimetric water content measurements may be used. To make the conversion from measured water content to suction it is necessary to have information on the gravimetric water retention at different suctions. The water retention at 1500 kPa may be estimated from the field clay percentage evaluation if dispersion of clay is relatively complete for the soils of concern. Commonly, the 1500 kPa retention is roughly 0.4 times the clay percentage. This relationship can be refined considerably as the soil material composition and organization is increasingly specified. Another rule of thumb is that the water content at air-dryness is about 10 percent of the clay percentage, assuming complete dispersion. Model-based curves that relate gravimetric water content and suction are available for many soils (Baumer, 1986). These curves may be used to determine upper water retention and the midpoint water retention, and to place the soil material in a water state class based on gravimetric water contents. Further such curves would be the basis in many instances for estimation of the water retention at 10 kPa from measurements at 33 kPa. Figure 3-10 shows a model-based curve for a medium-textured horizon and the relationship of water-state class limits to water contents determined from the desorption curve. The figure includes the results of a set of tests designed to provide local criteria for field and field office evaluation of water state. These will be discussed subsequently.

Commonly, gravimetric water content information is not available. Visual and tactile observations must suffice for the placement. Separation

FIGURE 3-10



Model-based curve for a medium-textured horizon and the relationships of water state class limits to water contents determined from the desorption curve.

between moist and wet and the distinction between the two subclasses of wet may be made visually, based on water-film expression and presence of free water. Similarly, the separation between very dry and moderately dry can be made by visual or tactile comparison of the soil material at the field water content and after air drying. The change on air drying should be quite small, if the soil material initially is in the very dry class.

Criteria are more difficult to formulate for soil material that is between the moist/wet and the moderately dry/very dry separations. Four tests follow that may be useful for mineral soils. The three tests that involve tactile examination are performed on soil material that has been manipulated and mixed. This manipulation and mixing may change the tactile qualities from that of weakly altered soil material. The change may be particularly large for dense soil. In the field, this limitation should be kept in mind.

Color value test. The crushed color value of the soil for an unspecified water state is compared to the color value at air dryness and while moderately moist or very moist. This test probably has usefulness only if the full range of color value from air dry to moderately moist exceeds one unit of color value. The change in color value and its interpretation depends on the water desorption characteristics of the soil material. For example, as the water retention at 1500 kPa increases, the difference between the minimum color value in the dry state and the very moist color value tends to decrease.

Ball test. A quantity of soil is squeezed firmly in the palm of the hand to form a ball about 3 to 4 cm in diameter. This is done in about five squeezes. The sphere should be near the maximum density that can be obtained by squeezing. Preparation of the ball will differ among people. The important point is that the procedure is consistent for an individual.

In one approach, the ball is dropped from progressively increasing heights onto a nonresilient surface. The height in centimeters at which rupture occurs is recorded. Usually heights above 100 cm are not measured. Additionally, the manner of rupture is recorded. If the ball flattens and does not rupture, the term "deforms" is used. If the ball breaks into about five or less units, the term "pieces" is used. Finally, if the number of units exceeds about five, the term "crumbles" is used.

Alternatively, penetration resistance may be used. The penetrometer is inserted in the ball in the same fashion as would be done for soil in place. This alternative is only applicable for medium and fine- textured soil materials at higher water contents because these soil materials are relatively plastic and not subject to cracking.

Rod test. The soil material is rolled between thumb and first finger or on a surface to form a rod 3 mm in diameter or less. This rod must remain intact while being held vertically from an end for recognition as a rod. Minimum length required is 2 cm. If the maximum length that can be formed is 2 to 5 cm, the rod is weak. If the maximum length equals or exceeds 5 cm, the rod is strong.

The rod test has close similarities to the plastic limit test (ASTM, 1984). Plastic limit values exceed the 1500 kPa retention at moderate clay contents and approach but are not commonly lower than the 1500 kPa retention at high clay contents. If a strong rod can be formed, the water content usually exceeds the 1500 kPa retention. The same is probably true for a weak rod. An adjustment is necessary if material of 2 to 0.5 mm is present because the plastic limit is measured on material that passes a number 40 sieve (0.43 mm in diameter).

Ribbon test. The soil material is smeared out between thumb and first finger to form a flattened body about 2 mm of thickness. The minimum length of a coherent unit required for recognition of a ribbon is 2 cm. If the maximum length is 2 to 4 cm, the ribbon is weak. If the maximum length equals or exceeds 4 cm, the ribbon is strong.

To establish criteria based on the foregoing tests it is highly desirable to apply the tests first to soil materials that are known to be at water-state class limits. The approach would parallel that used to maintain quality control of field texture evaluation. The first step to obtain such samples is to establish gravimetric water contents for the class limits (table 3-2). Soil material is prepared at these water contents. A known weight of soil

TABLE 3-3

Water state calibration tests on three soil materials differing in texture from central Nebraska.

Soil [a]	Sand Pct	Silt Pct	Clay Pct	Organic Matter Pct	MWR[b] Pct	1500 kPa-[b] Pct
Hastings	5	57	38	1.4	26.2	18.8
Lockton	53	33	14	1.6	12.9	7.6
Valentine	82	13	5	1.1	9.4	3.7

[a] Hastings is a fine, montmorillonitic, mesic Udic Argiustoll; Lockton is a fine-loamy over sandy or sandy-skeletal, mixed, mesic Cumulic Haplustoll; and Valentine is a mixed, mesic Typic Ustipsamment.
The Hastings sample is a silty clay loam; Lockton is a sandy loam; and Valentine is a loamy fine sand. All are from the upper subsoil. Montmorillonite is the dominant clay mineral. Soil materials with certain other clay mineralogies feel drier at 1500 kPa than do these samples.

TABLE 3-3 (continued)

Water Content Pct	Height cm	Ball Penetration Failure	Resistance MPa	Rod cm	Ribbon	Color Value
UWR						3
MWR	>100	Deform	1.1	7	7	3
1500 kPa	>100	Deform	Crack	1	3	4
0.8 x 1500 kPa	50	Pieces	Crack	No	1/2	4
Air Dry						5
>UWR						2.5
MWR	60	Pieces		No	3	3
1500 kPa	30	Pieces		No	2	3.5
0.8 x 1500 kPa	10	Crumbles		No	No	3.5
Air Dry						3.5
>UWR						3
MWR	< 2	Pieces		No	No	3.5
1500 kPa	< 5	Crumbles		No	No	4
0.8 x 1500 kPa						
Air Dry						4.5

b/ Both gravimetric. MWR: $\frac{\text{10 kPa plus 1500 kPa retention}}{2}$.

material at a measured, initially higher, water content than the desired final content is placed in a commercial, nylon oven-cooking bag. These bags pass from 1 to 10 grams per hour of water at room temperature, depending on the size, the air temperature, humidity, and movement. Water loss from the bag is continued until the predetermined weight (hence, desired water content) is reached. If long-term storage is desired, the soil is next transferred to glass canning jars. The soil material either may be dried from an initially higher field water content after passing through a number 4 sieve (4.8 mm) or may be air-dried, ground, wetted to above the desired final water content, and then dried. It is preferable to pass the soil through a number 4 sieve (4.8 mm) rather than a number 10 (2 mm). The natural organization is retained to a greater extent. As a result, the calibration sample feels more like it would under field conditions. For the higher suctions, consideration should be given to storage of the soil material for a day or two after the water content reduction to improve equilibration.

General relationships of the tests to water state, with the exception of the relationship of the rod test to 1500 kPa retention, have not been formulated and are probably not feasible. The tests may be applied to groupings of soils based on composition, and then locally applicable field criteria can be formulated. Table 3-3 illustrates much of the range in test results that may be expected within a soil survey in central Nebraska.

Natural Drainage Classes

Natural drainage class refers to the frequency and duration of wet periods under conditions similar to those under which the soil developed. Alteration of the water regime by man, either through drainage or irrigation, is not a consideration unless the alterations have significantly changed the morphology of the soil. The classes follow:

Excessively drained. Water is removed very rapidly. The occurrence of internal free water commonly is very rare or very deep. The soils are commonly coarse-textured and have *very high hydraulic conductivity* or are very shallow.

Somewhat excessively drained. Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse-textured and have *high saturated hydraulic conductivity* or are very shallow.

Well drained. Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants

throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness.

Moderately well drained. Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most mesophytic crops are affected. They commonly have a *moderately low* or *lower saturated hydraulic conductivity* in a layer within the upper 1 m, periodically receive high rainfall, or both.

Somewhat poorly drained. Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to *moderately deep* and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: *low* or *very low saturated hydraulic conductivity*, a high water table, additional water from seepage, or nearly continuous rainfall.

Poorly drained. Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of *low* or *very low saturated hydraulic conductivity* of nearly continuous rainfall, or of a combination of these.

Very poorly drained. Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.

TABLE 3-4

Frequency and Duration of Inundation Classes

Classes	Criteria
Frequency	
None (N)	No reasonable possibility
Rare (R)	1-5 times in 100 years
Occasional (O)	5-50 times in 100 years
Frequent (F)	≥ 50 times in 100 years
Common (C)	Occasional and frequent can be grouped for certain purposes and called common.
Duration	
Extremely Brief (BE)	< 4 hours (flooding only)
Very Brief (BV)	4-48 hours
Brief (B)	2-7 days
Long (L)	7 days-1 month
Very Long (LV)	≥ 1 month

Inundation Occurrence

Table 3-4 contains classes for frequency and for duration of inundation. A record of the month(s) during which the inundation occurs may be useful. Maximum depth of the inundation, as well as the flow velocity, may be helpful.

TABLE 3-5

Internal Free Water Occurrence Classes

Classes	Criteria
Thickness if perched	
Extremely Thin (TE)	<10 cm
Very Thin (TV)	10-30 cm
Thin (T)	30 cm-1 m
Thick (TK)	≥1 m
Depth	
Very Shallow (SV)	< 25 cm
Shallow (S)	25 cm-50 cm
Moderately Deep (DM)	50 cm-1 m
Deep (D)	1.0-1.5 m
Very Deep (DV)	≥ 1.5 m
Cumulative Annual Duration	
Absent (A)	Not observed
Very Transitory (TV)	Present <1 month
Transitory (T)	Present 1-3 months
Common (C)	Present 3-6 months
Persistent (PS)	Present 6-12 months
Permanent (PM)	Present Continuously

Internal Free Water Occurrence

Table 3-5 contains classes for the description of free water regime in soils. The term free water occurrence is used instead of *satiated wet* in order to facilitate discussion of interpretations. Classes are provided for internal free water occurrence that describe thickness if perched, depth to the upper boundary, and the aggregate time present in the calendar year. The free water need be present only in some parts of the horizon or layer to be recognized. If not designated as perched, it is assumed that the zone of free water occurs in all horizons or layers from its upper boundary to below 2 meters or to the depth of observation. Furthermore, artesian effects may be noted.

Water-State Annual Pattern

The water-state annual pattern is a description of field soil water over the year as applied to horizons, layers, or to standard depth zones. Using the classes of internal water states and of inundation, table 3-6 contains examples. Usually the use of the soil is indicated and the time interval is at least monthly. More general records may be constructed based on less specific soil uses and on soil concepts at a higher categorical level. Records may be constructed for classes of relative precipitation: wet—the wettest 2 years in 10; dry—the driest 2 years in 10; and average—the conditions 6 years in 10. Unless otherwise indicated, the class placement for relative precipitation would be based on the more critical part of the growing season for the vegetation specified in the use. The frequency and duration that the soil is inundated each month may be given.

Water Movement

Water movement concerns rates of flow into and within the soil and the related amount of water that runs off and does not enter the soil. Saturated hydraulic conductivity, infiltration rate, and surface runoff are part of the evaluation.

Saturated Hydraulic Conductivity

Water movement in soil is controlled by two factors: 1) the resistance of the soil matrix to water flow and 2) the forces acting on each element or unit of soil water. Darcy's law, the fundamental equation describing water movement in soil, relates the flow rate to these two factors. Mathematically, the general statement of Darcy's law for vertical, saturated flow is:

$$Q/At = -K_{sat}\, dH/dz$$

where the flow rate Q/At is what soil physicists call the flux density, i.e., the quantity of water Q moving past an area A, perpendicular to the direction of flow, in a time t. The vertical saturated hydraulic conductivity K_{sat} is the reciprocal, or inverse, of the resistance of the soil matrix to water flow. The term dH/dz is the hydraulic gradient, the driving force causing water to move in soil, the net result of all forces acting on the soil water. Rate of water movement is the product of the hydraulic conductivity and the hydraulic gradient.

A distinction is made between saturated and unsaturated hydraulic conductivity. Saturated flow occurs when the soil water pressure is positive; that is, when the soil matric potential is zero (satiated wet condition).

In most soils this situation takes place when about 95 percent of the total pore space is filled with water. The remaining 5 percent is filled with entrapped air. If the soil remains saturated for a long time (several months or longer) the percent of the total pore space filled with water may approach 100. Saturated hydraulic conductivity cannot be used to describe water movement under unsaturated conditions.

The vertical saturated hydraulic conductivity K_{sat} is of interest here; it is the factor relating soil water flow rate (flux density) to the hydraulic gradient and is a measure of the ease of water movement in soil. K_{sat} is the reciprocal of the resistance of soil to water movement. As the resistance increases, the hydraulic conductivity decreases. Resistance to water movement in saturated soil is primarily a function of the arrangement and size distribution of pores. Large, continuous pores have a lower resistance to flow (and thus a higher conductivity) than small or discontinuous pores. Soils with high clay content generally have lower hydraulic conductivities than sandy soils because the pore size distribution in sandy soil favors large pores even though sandy soils usually have higher bulk densities and lower total porosities (total pore space) than clayey soils. As illustrated by Poiseuille's law, the resistance to flow in a tube varies as the square of the radius. Thus, as a soil pore or channel doubles in size, its resistance to flow is reduced by a factor of 4; in other words its hydraulic conductivity increases 4-fold.

Hydraulic conductivity is a highly variable soil property. Measured values easily may vary by 10-fold or more for a particular soil series. Values measured on soil samples taken within centimeters of one another may vary by 10-fold or more. In addition, measured hydraulic conductivity values for a soil may vary dramatically with the method used for measurement. Laboratory determined values rarely agree with field measurements, the differences often being on the order of 100-fold or more. Field methods generally are more reliable than laboratory methods.

Because of the highly variable nature of soil hydraulic conductivity, a single measured value is an unreliable indicator of the hydraulic conductivity of a soil. An average of several values will give a reliable estimate which can be used to place the soil in a particular hydraulic conductivity class. Log averages (geometric means) should be used rather than arithmetic averages because hydraulic conductivity is a log normally distributed property. The antilog of the average of the logarithms of individual conductivity values is the log average, or geometric mean, and should be used to place a soil into the appropriate hydraulic conductivity class. Log averages are lower than arithmetic averages.

TABLE 3-6

Illustrative water state annual pattern. (Symbols are defined in table 3-2.)

Average - 6 years in 10

Depth cm	J	F	M	A	M	J	J	A	S	O	N	D
	Fine, montmorillonitic, mesic Typic Argiudoll [a]											
0-25	MM F	MM F	MM	MM	MM	MM	MS	DS	DS	MS	MM	MM F
25-50	MM F	MM F	MM F	MM	MM	MM	MM	MS	MS	MS	MS	MM
50-100	MS	MS	MM	MM	MM	MM	MM	MS	MS	MS	MS	MS
100-150	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM
150-200	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM
	Fine-loamy, mixed, thermic Typic Haploxeralf [b]											
0-30	MM	MM	MS	MS	DS	DS	D1[c]	D1	D1	D1	D1	MS
30-70	MM	MM	MM	MM	MS	DS	D1	D1	D1	DS	MS	MM
70-100	MV	MV	MM	MM	MM	MM	MS	D1	D1	D1	D1	MS
120-170	MM	MM	MM	MS	MS	MS	MS	D1	D1	D1	DS	MS

[a] Otoe County, Nebraska (Sautter, 1982). Sharpsburg silty clay loam, 2-5 percent slopes. Corn (Zea Mays) following corn. Assume contoured and terraced and retain over 20 percent residue cover. Disk twice in April. Field cultivate once. Plant May 1-15. Cultivate once or twice. Harvest November 1-15. Cattle graze after harvest. Based on a discussion with H.E. Sautter, soil scientist (retired), Syracuse, Nebraska. Monthly water states based on long-term field mapping experience and water balance computations. The Sharpsburg soil series pertains to the map unit illustrative of a consociation (appendix).

[b] San Diego Area, California (Bowman, 1973). Mean annual precipitation at Escondido is 344 mm and Thornthwaite potential evaporation is 840 mm. Study area in Fallbrook sandy loam, 5 to 9 percent slopes, eroded. The study area has slightly greater slope than the upper limit of the map unit. Vegetation is annual range, fair condition. Generalizations were made originally for the 1983 National Soil Survey Conference based on field measurements in 1966 by Nettleton et al. (1968), as interpreted by R.A. Dierking, soil correlator, Portland, Oregon. At the time, moderately dry and very dry were not distinguished.

[c] D1=DV + DM.

TABLE 3-6

Driest 2 years in 10

Depth cm	:J	:F	:M	:A	:M	:J	:J	:A	:S	:O	:N	:D
	Fine, montmorillonitic, mesic Typic Argiudoll [a]											
0-25	:MM	:MM	:MM	:MM	:MM	:MS	:DS :	DS	:DS	:MS	:MS	:MM
	:F	:F	:	:	:	:	:	:	:	:	:	:F
25-50	:MS	:MS	:MS	:MS	:MS	:MS	:MS	:MS	:MS	:MS	:MS	:MS
	:F	:F	:F	:	:	:	:	:	:	:	:	:
50-100	:MS	:MS	:MS	:MM	:MM	:MS	:MS	:MS	:MS	:MS	:MS	:MS
100-150	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM
150-200	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM :	:MM	:MM	:MM
	Fine-loamy, mixed, thermic Typic Haploxeralf [b]											
0-30	:MS	:MM	:MS	:MS	:DS	:DS	:D1	:D1	:D1	:D1	:D1	:DS
30-70	:MM	:MM	:MM	:MM	:MS	:DS	:D1	:D1	:D1	:D1	:MS	:MS
70-100	:MS	:MM	:MM	:MM	:MM	:MM	:MS	:D1	:D1	:D1	:D1	:DS
100-170	:MS	:MS	:MS	:MS	:MS	:MS	:MS	:D1	:D1	:D1	:D1	:D1

Wettest 2 years in 10

Depth cm	:J	:F	:M	:A	:M	:J	:J	:A	:S	:O	:N	:D
	Fine, montmorillonitic, mesic Typic Argiudoll [a]											
0-25	:MM	:MM	:MV	:MV	:MV	:MM	:MM	:MM	:MM :	:MM	:MM	:MM
	:F	:F	:	:	:	:	:	:	:	:	:	:F
25-50	:MM	:MM	:MV	:MV	:MM	:MM	:MM	:MM	:MM :	:MM	:MM	:MM
	:F	:F	:F	:	:	:	:	:	:	:	:	:
50-100	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM :	:MM	:MM	:MM
100-150	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM
150-200	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM	:MM
	Fine-loamy, mixed. thermic Typic Haploxeralf [b]											
0-30	:MM	:MM	:MM	:MS	:DS	:DS	:D1	:D1	:D1	:DS	:MS	:MM
30-70	:MV	:MV	:MM	:MM	:MS	:DS	:D1	:D1	:D1	:DS	:MM	:MV
70-100	:MV	:MV	:MM	:MM	:MM	:MM	:MS	:D1	:D1	:D1	:MS	:MM
120-170	:MM	:MM	:MS	:MS	:MS	:MS	:MS	:D1	:D1	:D1	:DS	:MS

TABLE 3-7

Saturated hydraulic conductivity classes.

Class	Ksat (μm/s)
Very High	≥ 100
High	10-100
Moderately High	1-10
Moderately Low	0.1-1
Low	0.01-0.1
Very Low	< 0.01

Hydraulic conductivity classes in this manual are defined in terms of vertical, saturated hydraulic conductivity. Table 3-7 defines the vertical, saturated hydraulic conductivity classes. The saturated hydraulic conductivity classes in this manual have a wider range of values than the classes of either the 1951 *Soil Survey Manual* or the 1971 *Engineering Guide*. The dimensions of hydraulic conductivity vary depending on whether the hydraulic gradient and flux density have mass, weight, or volume bases. Values can be converted from one basis to another with the appropriate conversion factor. Usually, the hydraulic gradient is given on a weight basis and the flux density on a volume basis and the dimensions of K_{sat} are length per time. The correct SI units thus are meters per second.[6] Micrometers per second are also acceptable SI units and are more convenient (table 3-7). Table 3-8 gives the class limits in commonly used units.

Hydraulic conductivity does not describe the capacity of soils in their natural setting to dispose of water internally. A soil placed in a very high class may contain free water because there are restricting layers below the soil or because the soil is in a depression where water from surrounding areas accumulates faster than it can pass through the soil. The water may actually move very slowly despite a high K_{sat}.

[6]The Soil Science Society of America prefers that all quantities be expressed on a mass basis. This results in K_{sat} units of kg s m^{-3}. Other units acceptable to the society are m^3 s kg^{-1}, the result of expressing all quantities on a volume basis, and m s^{-1}, the result of expressing the hydraulic gradient on a weight basis and flux density on a volume basis.

TABLE 3-8

Saturated hydraulic conductivity class limits in equivalent units.

µm/s	m/s	m/day	in/hr	cm/hr	$kg\ s\ m^{-3}$	$m^3 s\ kg^{-3}$
100.	$=10^{-4}$	864.	14.17	36.0	$1.02X10^{-2}$	$1.02X10^{-8}$
10.	$=10^{-5}$	86.4	1.417	3.60	$1.02X10^{-3}$	$1.02X10^{-9}$
1.	$=10^{-6}$	8.64	0.1417	0.360	$1.02X10^{-4}$	$1.02X10^{-10}$
0.1	$=10^{-7}$	0.864	0.01417	0.0360	$1.02X10^{-5}$	$1.02X10^{-11}$
0.01	$=10^{-8}$	0.0864	0.001417	0.00360	$1.02X10^{-6}$	$1.02X10^{-12}$

Guidelines for K_{sat} Class Placement

Measured values of K_{sat} are available from the literature or from researchers working on the same or similar soils. If measured values are available, their geometric means should be used for class placement.

Saturated hydraulic conductivity is a fairly easy, inexpensive, and straightforward measurement. If measured values are unavailable, a project to make measurements should be considered. Field methods are the most reliable. Standard methods for measurement of K_{sat} are described in Agronomy Monograph No. 9 (Klute and Dirksen, 1986, and Amoozegar and Warrick, 1986) and in SSIR 38 (Bouma et al., 1982).

Various researchers have attempted to estimate K_{sat} based on various soil properties. These estimation methods usually use one or more of the following soil physical properties: surface area, texture, structure, bulk density, and micromorphology. The success of the individual methods varies. Often a method does fairly well in a localized area. No one method works really well for all soils. Sometimes, measurement of the predictor variables is more difficult than measurement of hydraulic conductivity. Generally, adjustments must be made for "unusual" circumstances such as high sodium concentrations, certain clay mineralogies, and the presence of coarse fragments, fragipans, and other miscellaneous features.

The method presented here is very general (Rawls and Brakensiek, 1983). It has been developed from a statistical analysis of several thousand measurements in a variety of soils. Because the method is intended for a wide application, it must be used locally with caution. The results, often, must be adjusted based on experience and local conditions.

Figure 3-11 consists of three textural triangles that can be used for K_{sat} class placement, based on soil bulk density and texture. The center triangle is for use with soils having medium or average bulk densities. The triangles above and below are for soils with high and low bulk densities, respectively.

Figure 3-12 can be used to help determine which triangle in figure 3-11 to use. In each of the triangles, interpolation of the iso-bulk density lines yields a bulk density value for the particular soil texture. The triangle that provides the value closest to the measured or estimated bulk density determines the corresponding triangle in figure 3-11 that should be used.

The hydraulic conductivity of a particular soil horizon is estimated by finding the triangle (fig. 3-11), based on texture and bulk density, to which the horizon belongs. The bulk density class to which the horizon belongs in Fig. 3-11 determines the triangle to be used in Fig. 3-12.. The K_{sat} class can be determined immediately from the shading of the triangle. A numerical value of K_{sat} can be estimated by interpolating between the iso-K_{sat} lines; however, the values should be used with caution. The values should be used only to compare classes of soils and not as an indication of the K_{sat} of a particular site. If site values are needed, it is always best to make several measurements at the site.

The K_{sat} values given by the above procedure may need to be adjusted based on other known soil properties. Currently, there is little information available to provide adequate guidelines for adjusting the estimated K_{sat}. The soil scientist must use best judgement based on experience and the observed behavior of the particular soil.

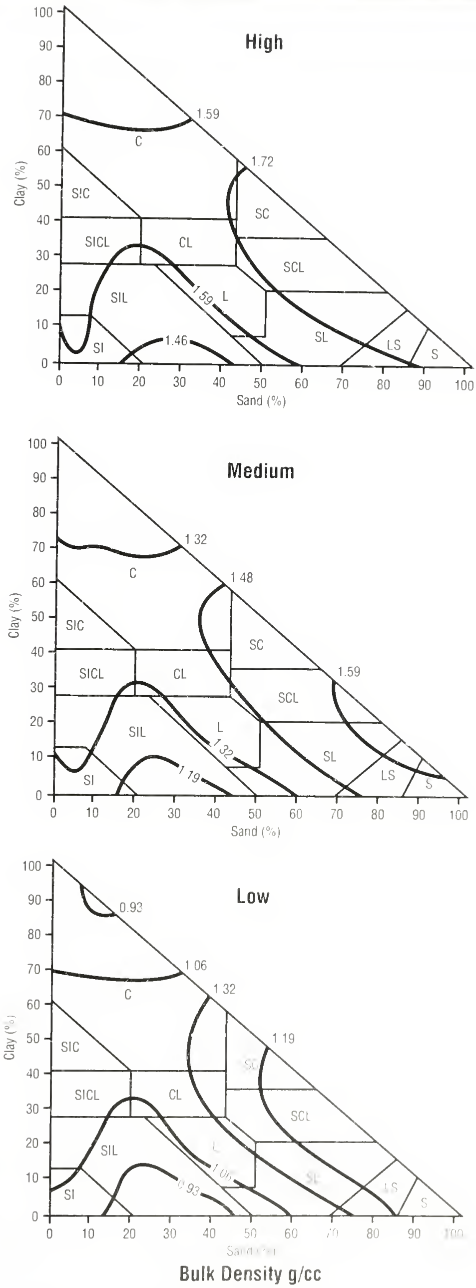
Hydraulic conductivity can be given for the soil as a whole, for a particular horizon, or for a combination of horizons. The horizon with the lowest value determines the hydraulic conductivity classification for the whole soil. If an appreciable thickness of soil above or below the horizon with the lowest value has significantly higher conductivity, then estimates for both parts are usually given.

Infiltration

Infiltration is the process of downward water entry into the soil. The values are usually sensitive to near surface conditions as well as to the antecedent water state. Hence, they are subject to significant change with soil use and management and time.

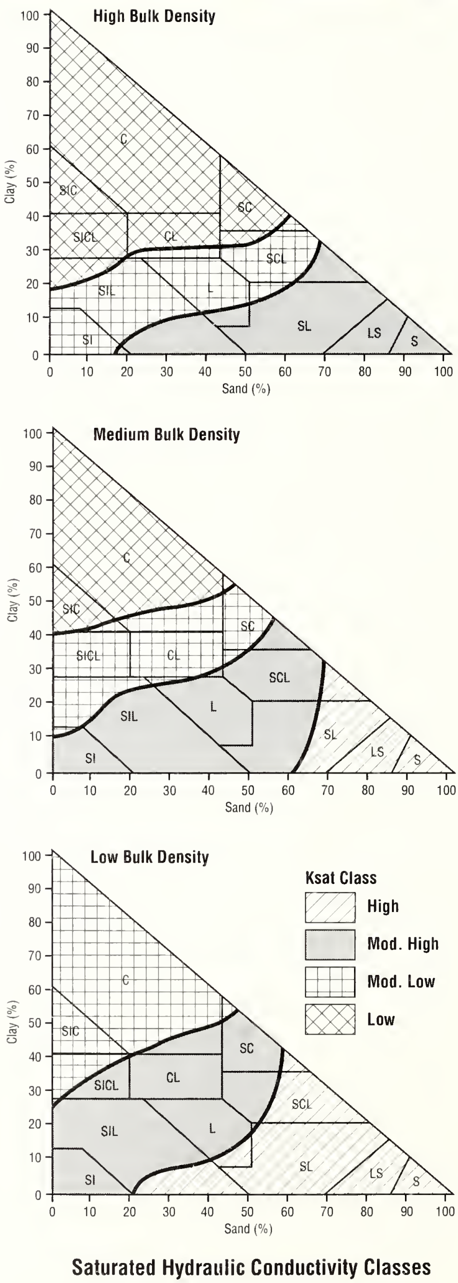
Infiltration stages.—Three stages of infiltration may be recognized—preponded, transient ponded, and steady ponded. *Preponded infiltration* pertains to downward water entry into the soil under conditions that free water is absent on the land surface. The rate of water addition determines

FIGURE 3-11



Saturated hydraulic conductivity classes (Rawls and Brakensiek, 1983). A clay loam with a bulk density of 1.40 g/cc and 35 percent both sand and clay falls in the medium bulk density class.

FIGURE 3-12



Bulk density and texture relationships.

the rate of water entry. If rainfall intensity increases twofold, then the infiltration increases twofold. In this stage, surface-connected macropores are relatively ineffective in transporting water downward. No runoff occurs during this stage.

As water addition continues, the point may be reached where free water occurs on the ground surface. This condition is called ponding. The term in this context is less restrictive than its use in inundation. The free water may be restricted to depressions and be absent from the majority of the ground surface. Once ponding has taken place, the control over the infiltration shifts from the rate of water addition to characteristics of the soil. Surface-connected nonmatrix and subsurface-initiated cracks then become effective in transporting water downward.

Infiltration under conditions where free water is present on the ground surface is referred to as *ponded infiltration*. In the initial stages of ponded infiltration, the rate of water entry usually decreases appreciably with time because of the deeper wetting of the soil, which results in a reduced suction gradient, and the closing of cracks and other surface-connected macropores. *Transient ponded infiltration* is the stage at which the ponded infiltration decreases markedly with time. After long continued wetting under ponded conditions, the rate of infiltration becomes steady. This stage is referred to as *steady ponded infiltration*. Surface-connected cracks would be closed, if reversible. The suction gradient would be small and the driving force reduced to near that of the gravitational gradient. Assuming the absence of ice and of zones of free water within moderate depths and that surface or near surface features (crust, for example) do not control infiltration, the minimum saturated hydraulic conductivity within a depth of 1/2 to 1 meter should be a useful predictor of steady ponded infiltration rate.

Minimum Annual Steady Ponded Infiltration.—The steady ponded infiltration rate while the soil is in the wettest state that regularly occurs while not frozen is called the *minimum annual steady ponded infiltration rate*. The quantity is subject to reduction because of the presence of free water at shallow depths if this is a predictable feature of the soil. Allowance for the effect of free water differentiates the quantity from minimum saturated hydraulic conductivity for the upper meter of the soil. The minimum annual steady ponded infiltration rate has application for prediction of runoff at the wettest times of the year when the runoff potential should be the highest.

Hydrologic soil groups.—Hydrologic soil groups are employed in the computation of runoff by the Curve Number method. Minimum annual steady ponded infiltration rate for a bare ground surface determines the hydrologic soil groups. Table 3-9 contains criteria for class placement.

TABLE 3-9

Criteria for Placement in Hydrologic Soil Groups

Hydrologic Soil Group	Criteria a/
A	Saturated hydraulic conductivity is *very high* or in the upper half of high and internal free water occurrence is *very deep.*
B	Saturated hydraulic conductivity is in the lower half of *high* or in the upper half of *moderately high* and free water occurrence is *deep* or *very deep.*
C	Saturated hydraulic conductivity is in the lower half of *moderately high* or in the upper half of *moderately low* and internal free water occurrence is deeper than *shallow.*
D	Saturated hydraulic conductivity is below the upper half of *moderately low,* and/or internal free water occurrence is *shallow* or *very shallow* and *transitory* through *permanent.*

[a/]The criteria are guidelines only. They are based on the assumption that the minimum saturated hydraulic conductivity occurs within the uppermost 0.5 m. If the minimum occurs between 0.5 and 1 m, then saturated hydraulic conductivity for the purpose of placement is increased one class. If the minimum occurs below 1 m, then the value for the soil is based on values above 1 m using the rules as previously given.

The Green-Ampt model is an example of a model used to compute infiltration rate. The model assumes that infiltrating water uniformly wets to a depth and stops abruptly at a front. This front moves downward as infiltration proceeds. The soil above the wetting front is in the satiated wet condition throughout the wetted zone.

The equation (Rawls and Brackensick, 1983) to describe infiltration is:

$$f = Ka \left(1 + \frac{MxS}{F}\right)$$

Ka is the hydraulic conductivity for satiated, but not necessarily saturated conditions; M is the porosity at a particular water state that is available to be filled with water; S is the effective suction at the wetting front; and F is the cumulative infiltration. The hydraulic conductivity at satiation is somewhat lower than the saturated value because of the presence of entrapped air. The available porosity, M, changes for surficial horizons with the bulk density and for all horizons with the water state. It is, therefore, sensitive to soil use which may affect both bulk density of surficial horizons and the antecedent water state. The value of S, the effective suction head at the wetting front, is determined largely by the texture and is a tabulated quantity. The cumulative infiltration, F, increases with time as infiltration proceeds. A consequence of the increase in the cumulative infiltration is that the infiltration rate, f, decreases with time. As the cumulative infiltration becomes large and the depth of wetting considerable, the infiltration rate should approach the value of the hydraulic conductivity for the satiated condition.

Surface Runoff

Surface runoff refers to the loss of water from an area by flow over the land surface. Surface runoff differs from subsurface flow or interflow that results when infiltrated water encounters a zone with lower perviousness than the soil above. The water accumulates above this less pervious zone and may move laterally if conditions are favorable for the occurrence of free water.

Index Surface Runoff Classes.—Historically, a set of runoff classes have been employed "as determined by the characteristics of soil slope, climate, and cover" (Soil Survey Staff, 1951). Table 3-10 contains a set of classes that parallel the sense of how the previous runoff classes were applied but with some changes in the written definitions. The current concept is referred to as index surface runoff. The concept indicates relative runoff for very specific conditions. The soil surface is assumed to be bare and surface water retention due to irregularities in the ground surface is low. Steady ponded infiltration rate is the applicable infiltration stage. Ice is assumed to be absent unless otherwise indicated. Finally, both the maximum bulk density in the upper 25 cm and the bulk density of the uppermost few centimeters are assumed within the limits specified for the mapping concept.

The concept assumes a standard storm or amount of water addition from snowmelt of 50 mm in a 24-hour period with no more than 25 mm in any single 1-hour period. Additionally, a standardized antecedent water state condition prior to the water addition is assumed: the soil is conceived to be *very moist* or *wet* to the base of the soil, to 1/2 m, or through the hori-

zon or layer with minimum saturated hydraulic conductivity within 1 meter, whichever is the greatest depth. If the minimum saturated hydraulic conductivity of the soil occurs below 1 meter, it is disregarded and the minimum "to and including 1 m" is employed. For soils with seasonal *shallow* or *very shallow* free water, *very low* saturated hydraulic conductivity is assumed in the application of the guidelines in table 3-10.

Class placement (table 3-10) depends only on slope and on saturated hydraulic conductivity. Table 3-10 is based on the minimum saturated hydraulic conductivity for the soil at or above 1/2 m. If the minimum for the soil occurs between 1/2 and 1 m, the runoff should be reduced by one class (from *medium* to *low*, for example). If the lowest saturated hydraulic conductivity occurs at 1 m or deeper, the lowest value to 1 m depth should be employed rather than the lowest value for the soil.

Hydrologic models.—The set of index surface runoff classes are relative and not quantitative. Actual runoff estimates require quite different approaches. To make quantitative surface runoff estimates requires application of a hydrologic model to a watershed. Most hydrologic models involve a balancing between precipitation and infiltration rates with runoff being the difference after a correction for retention of water on the land surface and on vegetation. In the more rigorous models, the infiltration is predicted from soil physical quantities and estimates of infiltration, evapotranspiration, and deep percolation are used to predict continuously the soil water state.

An empirical model in current use is based on an analysis of a large number of runoff events for watersheds (Soil Conservation Service, 1972). A family of curves was formulated from these data to show the relationship between cumulative daily runoff and cumulative daily rainfall. Each of the family of curves is numbered—hence the name, Curve Number Model. The curves that describe the runoff-precipitation relationship are affected by the sum of the removals from the rainfall by infiltration, by retention on vegetation, and by storage in depressions on the land surface. If no removal of the added water has occurred, then the relationship between daily runoff and daily rainfall is a straight line at 45 degrees. As the removal increases, the departure from a 45 degree line increases. The specific curve to employ is determined by evaluation of these factors: the assumed ground surface conditions as determined by the vegetation and cultural practices, the hydrologic soil group (table 3-9), and the water storage capacity. The first factor is evaluated from land use, vegetation, and land treatment or farming practices. The second is an assessment commonly made for a soil series. The third factor is evaluated from the rainfall-evaporation balance for several days preceding the precipitation event.

TABLE 3-10

Index surface runoff classes based on slope gradient and saturated hydraulic conductivity

Slope Gradient	Saturated Hydraulic Conductivity Class *a, b*					
Pct.	*Very High*	*High*	*Mod. High*	*Mod. Low*	*Low*	*Very Low*
Concave *c*	N	N	N	N	N	N
<1	N	N	N	L	M	H
1- 5	N	LV	L	M	H	HV
5-10	LV	L	M	H	HV	HV
10- 20	LV	L	M	H	HV	HV
≥ 20	L	M	H	HV	HV	HV

a Abbreviations: Negligible-N; Very Low-LV; Low-L; Medium-M; High-H; and Very High-HV.

b Consult table 3-7 for definitions.

c Areas from which no or very little water escapes by flow over the ground surface.

Soil Temperature

Soil temperature exerts a strong influence on biological activities. It also influences the rates of chemical and physical processes within the soil. When the soil is frozen, biological activities and chemical processes essentially stop. Physical processes that are associated with ice formation are active if unfrozen zones are associated with freezing zones. Below a soil temperature of about 5 °C, growth of roots of most plants is negligible. In areas where soils have permanently frozen layers near the surface, however, even large roots of adapted plants are present immediately above the frozen layer late in the summer. Most plants grow best within a restricted range of soil and air temperature. Knowledge of soil and air temperature is essential in understanding soil-plant relation-

ships. Temperature changes with time, as does the soil-water state. It generally differs from layer to layer at any given time.

Characteristics of Soil Temperature

Heat is both absorbed at and lost from the surface of the soil. Temperature at the surface can change in daily cycles. The soil transmits heat downward when the temperature near the surface is higher than the temperature below and heat upward when the temperature is warmer within the soil than at the surface. Soil temperatures at various depths within the soil follow cycles. The cycles deeper in the soil lag behind those near the surface. The daily cycles decrease in amplitude as depth increases and are scarcely measurable below 50 cm in most soils. Seasonal cycles are evident to much greater depths if seasonal air temperature differences are pronounced, but the temperature at a depth of 10 m is nearly constant in most soils and is about the same as the mean annual temperature of the soil above.

Soil temperature varies from layer to layer at a given site at a given time; yet, if the average annual temperatures at different depths in the same pedon are compared, they usually do not differ. Mean annual temperature is one of several useful values that describe the temperature regime of a soil.

The seasonal fluctuation of soil temperature is a characteristic of a soil. Soil temperature fluctuates little seasonally near the equator; it fluctuates widely as seasons change in the middle and high latitudes. Mean seasonal temperatures can be used to characterize soil temperature. Seasonal temperature differences decrease and the seasonal cycles lag progressively as depth increases.

For soils that freeze in winter, soil temperature is influenced by the release of heat when water changes from the liquid to the solid form. This releases about 80 calories per gram of water. The heat must be dissipated before the water in soil freezes. The rate of thaw of frozen soils is slower, because heat is required to warm the soil in order to melt the ice. In areas of heavy snowfall, the snow provides an insulating blanket and soils do not freeze as deeply or may not freeze at all.

Many factors influence soil temperature. They include amount, intensity, and distribution of precipitation; daily and monthly fluctuations in air temperature; insolation; kinds, amounts, and persistence of vegetation; duration of moisture states and snow cover; kinds of organic deposits; soil color; aspect and gradient of slope; elevation; and ground water. All of these factors may be described in a soil survey if they are significant.

Estimating Soil Temperature

Mean annual soil temperature in temperate, humid, continental climates can be approximated by adding 1 °C to the mean annual air temperature reported by standard meteorological stations at locations representative of the soil to be characterized. The mean annual soil temperature at a given place can be estimated more reliably by a single reading at a depth of 10 m. If water in wells is at depths between 10 and 20 m, the temperature of the water usually gives a close estimate of mean annual soil temperature. Mean annual soil temperature can also be estimated closely from the average of four readings at about 50 cm or greater depth, equally spaced throughout the year.

The mean soil temperature for summer can be estimated by averaging three measurements taken at a constant depth between 50 cm and 1 m on the 15th of each of the three months of the season. Similar methods may be used to estimate soil temperature for other seasons. These methods give values subject to minor variation caused by differences in vegetation (particularly density of canopy), ground water, snow, aspect, rain, unusual weather conditions, and other factors. Tests for nearly level, freely drained soils, both grass-covered and cultivated, produce comparable values. Over the usual period of a soil survey, systematic studies can be made to establish temperature relationships in the survey area.

Designations for Horizons and Other Layers

Soils vary widely in the degree to which horizons are expressed. Relatively fresh geologic formations, such as fresh alluvium, sand dunes, or blankets of volcanic ash, may have no recognizable genetic horizons, although they may have distinct layers that reflect different modes of deposition. As soil formation proceeds, horizons may be detected in their early stages only by very careful examination. As age increases, horizons generally are more easily identified in the field. Only one or two different horizons may be readily apparent in some very old, deeply weathered soils in tropical areas where annual precipitation is high.

Layers of different kinds are identified by symbols. Designations are provided for layers that have been changed by soil formation and for those that have not. Each horizon designation indicates either that the original material has been changed in certain ways or that there has been little or no change. The designation is assigned after comparison of the observed properties of the layer with properties inferred for the material before it was affected by soil formation. The processes that have caused

the change need not be known; properties of soils relative to those of an estimated parent material are the criteria for judgment. The parent material inferred for the horizon in question, not the material below the solum, is used as the basis of comparison. The inferred parent material commonly is very similar to, or the same as, the soil material below the solum.

Designations show the investigator's interpretations of genetic relationships among the layers within a soil. Layers need not be identified by symbols for a good description; yet, the usefulness of soil descriptions is greatly enhanced by the proper use of designations.

Designations are not substitutes for descriptions. If both designations and adequate descriptions of a soil are provided, the reader has the interpretation made by the person who described the soil and also the evidence on which the interpretation was based.

Genetic horizons are not equivalent to the diagnostic horizons of *Soil Taxonomy*. Designations of genetic horizons express a qualitative judgment about the kind of changes that are believed to have taken place. Diagnostic horizons are quantitatively defined features used to differentiate among taxa. Changes implied by genetic horizon designations may not be large enough to justify recognition of diagnostic criteria. For example, a designation of Bt does not always indicate an argillic horizon. Furthermore, the diagnostic horizons may not be coextensive with genetic horizons.

Three kinds of symbols are used in various combinations to designate horizons and layers. These are capital letters, lower case letters, and Arabic numerals. Capital letters are used to designate the master horizons and layers; lower case letters are used as suffixes to indicate specific characteristics of master horizons and layers; and Arabic numerals are used both as suffixes to indicate vertical subdivisions within a horizon or layer and as prefixes to indicate discontinuities.

Master Horizons and Layers

The capital letters O,A,E,B,C, and R represent the master horizons and layers of soils. The capital letters are the base symbols to which other characters are added to complete the designations. Most horizons and layers are given a single capital letter symbol; some require two.

O horizons or layers: *Layers dominated by organic material. Some are saturated with water for long periods or were once saturated but are now artificially drained; others have never been saturated.*

Some O layers consist of undecomposed or partially decomposed litter, such as leaves, needles, twigs, moss, and lichens, that has been deposited

on the surface; they may be on top of either mineral or organic soils. Other O layers, are organic materials that were deposited under saturated conditions and have decomposed to varying stages (Soil Survey Staff, 1975). The mineral fraction of such material is only a small percentage of the volume of the material and generally is much less than half of the weight. Some soils consist entirely of material designated as O horizons or layers.

An O layer may be on the surface of a mineral soil or at any depth beneath the surface, if it is buried. A horizon formed by illuviation of organic material into a mineral subsoil is not an O horizon, although some horizons that formed in this manner contain much organic matter.

A horizons: *Mineral horizons that formed at the surface or below an O horizon, that exhibit obliteration of all or much of the original rock structure, and that show one or more of the following: (1) an accumulation of humified organic matter intimately mixed with the mineral fraction and not dominated by properties characteristic of E or B horizons (defined below) or (2) properties resulting from cultivation, pasturing, or similar kinds of disturbance.*

If a surface horizon has properties of both A and E horizons but the feature emphasized is an accumulation of humified organic matter, it is designated an A horizon. In some places, as in warm arid climates, the undisturbed surface horizon is less dark than the adjacent underlying horizon and contains only small amounts of organic matter. It has a morphology distinct from the C layer, although the mineral fraction is unaltered or only slightly altered by weathering. Such a horizon is designated A because it is at the surface; however, recent alluvial or eolian deposits that retain rock structure[7] are not considered to be an A horizon unless cultivated.

E horizons: *Mineral horizons in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles. These horizons exhibit obliteration of all or much of the original rock structure.*

An E horizon is usually, but not necessarily, lighter in color than an underlying B horizon. In some soils the color is that of the sand and silt particles, but in many soils coatings of iron oxides or other compounds

[7]Rock structure includes fine stratification in unconsolidated, or pseudomorphs, of weathered minerals that retain their positions relative to each other and to unweathered minerals in saprolite from consolidated rocks.

mask the color of the primary particles. An E horizon is most commonly differentiated from an overlying A horizon by its lighter color. It generally has less organic matter than the A horizon. An E horizon is most commonly differentiated from an underlying B horizon in the same sequum by color of higher value, by lower chroma or both, by coarser texture, or by a combination of these properties. An E horizon is commonly near the surface below an O or A horizon and above a B horizon, but the symbol E can be used for eluvial horizons within or between parts of the B horizon or for those that extend to depths greater than normal observation if the horizon has resulted from soil genesis.

B horizons: *Horizons that formed below an A, E,, or O horizon and are dominated by obliteration of all or much of the original rock structure and show one or more of the following:*

(1) illuvial concentration of silicate clay, iron, aluminum, humus, carbonates, gypsum, or silica, alone or in combination;
(2) evidence of removal of carbonates;
(3) residual concentration of sesquioxides;
(4) coatings of sesquioxides that make the horizon conspicuously lower in value, higher in chroma, or redder in hue than overlying and underlying horizons without apparent illuviation of iron;
(5) alteration that forms silicate clay or liberates oxides or both and that forms granular, blocky, or prismatic structure if volume changes accompany changes in moisture content; or
(6) brittleness.

All kinds of B horizons are subsurface horizons or were originally. Included as B horizons where contiguous to another genetic horizon are layers of illuvial concentration of carbonates, gypsum, or silica that are the result of pedogenic processes (these layers may or may not be cemented) and brittle layers that have other evidence of alteration, such as prismatic structure or illuvial accumulation of clay.

Examples that are not B horizons are layers in which clay films coat rock fragments or are on finely stratified unconsolidated sediments, whether the films were formed in place or by illuviation, layers into which carbonates have been illuviated but are not contiguous to an overlying genetic horizon, and layers with gleying but no other pedogenic changes.

C horizons or layers : *Horizons or layers, excluding hard bedrock, that are little affected by pedogenic processes and lack properties of O, A, E, or B horizons. The material of C layers may be either like or unlike that from which the*

solum presumably formed. The C horizon may have been modified even if there is no evidence of pedogenesis.

Included as C layers are sediment, saprolite, unconsolidated bedrock, and other geologic materials that commonly are uncemented (table 3-14) and exhibit low or moderate excavation difficulty (table 3-21). Some soils form in material that is already highly weathered. If such material does not meet the requirements of A, E, or B horizons, it is designated C. Changes not considered pedogenic are those not related to overlying horizons. Layers that have accumulations of silica, carbonates, or gypsum or more soluble salts are included in C horizons, even if *indurated* (table 3-14). If the indurated layers are obviously affected by pedogenic processes, they are a B horizon.

R layers: *Hard Bedrock*

Granite, basalt, quartzite and indurated limestone or sandstone are examples of bedrock that are designated R. These layers are cemented and excavation difficulty exceeds moderate. The R layer is sufficiently coherent when moist to make hand digging with a spade impractical, although it may be chipped or scraped. Some R layers can be ripped with heavy power equipment. The bedrock may contain cracks that generally are too few and too small to allow roots to penetrate at intervals of less than 10 cm. The cracks may be coated or filled with clay or other material.

Transitional and Combination Horizons

Horizons dominated by properties of one master horizon but having subordinate properties of another. Two capital letter symbols are used, as AB, EB, BE, or BC. The master horizon symbol that is given first designates the kind of horizon whose properties dominate the transitional horizon. An AB horizon, for example, has characteristics of both an overlying A horizon and an underlying B horizon, but it is more like the A than like the B.

In some cases, a horizon can be designated as transitional even if one of the master horizons to which it is apparently transitional is not present. A BE horizon may be recognized in a truncated soil if its properties are similar to those of a BE horizon in a soil in which the overlying E horizon has not been removed by erosion. A BC horizon may be recognized even if no underlying C horizon is present; it is transitional to assumed parent material.

Horizons in which distinct parts have recognizable properties of the two kinds of master horizons indicated by the capital letters. The two capital letters are separated by a virgule (/), as E/B, B/E, or B/C. Most of the individual parts of one of the components are surrounded by the other.

The designation may be used even though horizons similar to one or both of the components are not present, if the separate components can be recognized. The first symbol is that of the horizon that makes up the greater volume.

Single sets of designators do not cover all situations; therefore, some improvising may be necessary. For example, Alfic Udipsamments have lamellae that are separated from each other by eluvial layers. Because it is generally not practical to describe each lamellae and eluvial layer as a separate horizon, the horizons are combined but the components are described separately. One horizon would then contain several lamellae and eluvial layers and might be designated as an *E* and *Bt* horizon. The complete horizon sequence for this soil could be: Ap-Bw-E and Bt1-E and Bt2-C.

Subordinate Distinctions Within Master Horizons and Layers

Lower case letters are used as suffixes to designate specific kinds of master horizons and layers. The word "accumulation" is used in many of the definitions in the sense that the horizon must have more of the material in question than is presumed to have been present in the parent material. The symbols and their meanings are as follows:

a *Highly decomposed organic material*
This symbol is used with "O" to indicate the most highly decomposed of the organic materials. The rubbed fiber content is less than about 17 percent of the volume.

b *Buried genetic horizon*
This symbol is used in mineral soils to indicate identifiable buried horizons with major genetic features that were formed before burial. Genetic horizons may or may not have formed in the overlying material, which may be either like or unlike the assumed parent material of the buried soil. The symbol is not used in organic soils or to separate an organic layer from a mineral layer.

c *Concretions or nodules*
This symbol is used to indicate a significant accumulation of concretions or of nodules. Cementation is required. The cementing agent is not specified except it cannot be silica. This symbol is not used if concretions or nodules are dolomite or calcite or more soluble salts, but it is used if the nodules or concretions are enriched in minerals that contain iron, aluminum, manganese, or titanium.

d *Physical root restriction*

This symbol is used to indicate root restricting layers in naturally occurring or manmade unconsolidated sediments or materials such as dense basal till, plow pans, and other mechanically compacted zones.

e *Organic material of intermediate decomposition*

This symbol is used with "O" to indicate organic materials of intermediate decomposition. Rubbed fiber content is 17 to 40 percent of the volume.

f *Frozen soil*

This symbol is used to indicate that the horizon or layer contains permanent ice. Symbol is not used for seasonally frozen layers or for "dry permafrost" (material that is colder than O° C but does not contain ice).

g *Strong gleying*

This symbol is used to indicate either that iron has been reduced and removed during soil formation or that saturation with stagnant water has preserved a reduced state. Most of the affected layers have chroma of 2 or less and many have redox concentrations. The low chroma can be the color of reduced iron or the color of uncoated sand and silt particles from which iron has been removed. Symbol "g" is not used for soil materials of low chroma, such as some shales or E horizons, unless they have a history of wetness. If "g" is used with "B," pedogenic change in addition to gleying is implied. If no other pedogenic change in addition to gleying has taken place, the horizon is designated Cg.

h *Illuvial accumulation of organic matter*

This symbol used with "B" to indicate the accumulation of illuvial, amorphous, dispersible organic matter-sesquioxide complexes. The sesquioxide component coats sand and silt particles. In some horizons, coatings have coalesced, filled pores, and cemented the horizon. The symbol "h" is also used in combination with "s" as "Bhs" if the amount of sesquioxide component is significant but value and chroma of the horizon are 3 or less.

i *Slightly decomposed organic material*

This symbol is used with "O" to indicate the least decomposed of the organic materials. Rubbed fiber content is more than about 40 percent of the volume.

k *Accumulation of carbonates*
This symbol is used to indicate the accumulation of alkaline earth carbonates, commonly calcium carbonate.

m *Cementation or induration*
This symbol is used to indicate continuous or nearly continuous cementation. The symbol is used only for horizons that are more than 90 percent cemented, although they may be fractured. The layer is physically root restrictive. The single predominant or codominant cementing agent may be indicated by using defined letter suffixes, singly or in pairs. If the horizon is cemented by carbonates, "km" is used; by silica, "qm"; by iron, "sm"; by gypsum, "ym"; by both lime and silica, "kqm"; by salts more soluble than gypsum, "zm."

n *Accumulation of sodium*
This symbol is used to indicate an accumulation of exchangeable sodium.

o *Residual accumulation of sesquioxides*
This symbol is used to indicate residual accumulation of sesquioxides.

p *Tillage or other disturbance*
This symbol is used to indicate a disturbance of the surface layer by mechanical means, pasturing, or similar uses. A disturbed organic horizon is designated Op. A disturbed mineral horizon is designated Ap even though clearly once an E, B, or C horizon.

q *Accumulation of silica*
This symbol is used to indicate an accumulation of secondary silica.

r *Weathered or soft bedrock*
This symbol is used with "C" to indicate root restrictive layers of soft bedrock or saprolite, such as weathered igneous rock; partly consolidated soft sandstone; siltstone; and shale. Excavation difficulty is low or moderate.

s *Illuvial accumulation of sesquioxides and organic matter*
This symbol is used with "B" to indicate the accumulation of illuvial, amorphous, dispersible organic matter-sesquioxide complexes if both the organic matter and sesquioxide components are significant and the value and chroma of the horizon is more than

3. The symbol is also used in combination with "h" as "Bhs" if both the organic matter and sesquioxide components are significant and the value and chroma are 3 or less.

ss *Presence of slickensides*

This symbol is used to indicate the presence of slickensides. Slickensides result directly from the swelling of clay minerals and shear failure, commonly at angles of 20 to 60 degrees above horizontal. They are indicators that other vertic characteristics, such as wedge-shaped peds and surface cracks, may be present.

t *Accumulation of silicate clay*

This symbol is used to indicate an accumulation of silicate clay that has formed and subsequently translocated within the horizon or has been moved into the horizon by illuviation, or both. At least some part should show evidence of clay accumulation in the form of coatings on surfaces of peds or in pores, or as lamellae, or bridges between mineral grains.

v *Plinthite*

This symbol is used to indicate the presence of iron-rich, humus-poor, reddish material that is firm or very firm when moist and that hardens irreversibly when exposed to the atmosphere and to repeated wetting and drying.

w *Development of color or structure*

This symbol is used with "B" to indicate the development of color or structure, or both, with little or no apparent illuvial accumulation of material. It should not be used to indicate a transitional horizon.

x *Fragipan character*

This symbol is used to indicate genetically developed layers that have a combination of firmness, brittleness, very coarse prisms with few to many bleached vertical faces, and commonly higher bulk density than adjacent layers. Some part is physically root restrictive.

y *Accumulation of gypsum*

This symbol is used to indicate the accumulation of gypsum.

z *Accumulation of salts more soluble than gypsum*

This symbol is used to indicate an accumulation of salts more soluble than gypsum.

Conventions for using letter suffixes.—Many master horizons and layers that are symbolized by a single capital letter will have one or more lower case letter suffixes. The following rules apply:

Letter suffixes should immediately follow the capital letter.

More than three suffixes are rarely used.

When more than one suffix is needed, the following letters, if used, are written first: a, e, h, i, r, s, t, and w. Except for the Bhs or Crt[8] horizons, none of these letters are used in combination in a single horizon.

If more than one suffix is needed and the horizon is not buried, these symbols, if used, are written last: c, d, f, g, m, v, and x. Some examples: Btg, Bkm, and Bsm.

If a horizon is buried, the suffix "b" is written last. Suffix "b" is used only for buried mineral soils.

A B horizon that has significant accumulation of clay and also shows evidence of development of color or structure, or both, is designated Bt ("t" has precedence over "w," "s," and "h"). A B horizon that is gleyed or that has accumulations of carbonates, sodium, silica, gypsum, salts more soluble than gypsum, or residual accumulation or sesquioxides carries the appropriate symbol—g, k, n, q, y, z, or o. If illuvial clay is also present, "t" precedes the other symbol: Btg.

Suffixes "h," "s," and "w" are not normally used with g, k, n, q, y, z, or o.

Vertical subdivision.—Commonly a horizon or layer designated by a single letter or a combination of letters needs to be subdivided. The Arabic numerals used for this purpose always follow all letters. Within a C, for example, successive layers could be C1, C2, C3, and so on; or, if the lower part is gleyed and the upper part is not, the designations could be C1-C2-Cg1-Cg2 or C-Cg1-Cg2-R.

These conventions apply whatever the purpose of subdivision. In many soils, horizons that would be identified by one unique set of letters are subdivided on the basis of evident morphological features, such as

[8]Indicates weathe[illegible] or saprolite in which clay films are present.

structure, color, or texture. These divisions are numbered consecutively. The numbering starts with 1 at whatever level in the profile any element of the letter symbol changes. Thus Bt1-Bt2-Btk1-Btk2 is used, not Bt1-Bt2-Btk3-Btk4. The numbering of vertical subdivisions within a horizon is not interrupted at a discontinuity (indicated by a numerical prefix) if the same letter combination is used in both materials: Bs1-Bs2-2Bs3-2Bs4 is used, not Bs1-Bs2-2Bs1-2Bs2.

Sometimes, thick layers are subdivided during sampling for laboratory analyses even though differences in morphology are not evident in the field. These layers need to be identified. This is done by following the convention of using arabic numerals to identify the subdivision. The arabic numerals would follow the letter designations and be a part of the horizon designation. For example, four layers of a Bt2 horizon sampled by 10-cm increments would be designated Bt21, Bt22, Bt23, and Bt24. The Bt2 horizon is subdivided for sampling purposes only.

Discontinuities.—In mineral soils Arabic numerals are used as prefixes to indicate discontinuities. Wherever needed, they are used preceding A, E, B, C, and R. These prefixes are distinct from Arabic numerals used as suffixes to denote vertical subdivisions.

A discontinuity is a significant change in particle-size distribution or mineralogy that indicates a difference in the material from which the horizons formed and/or a significant difference in age, unless that difference in age is indicated by the suffix "b." Symbols to identify discontinuities, are used only when they will contribute substantially to the reader's understanding of relationships among horizons. Stratification common to soils formed in alluvium is not designated as discontinuity, unless particle size distribution differs markedly (strongly contrasting particle-size class, as defined by Soil Taxonomy) from layer to layer even though genetic horizons have formed in the contrasting layers.

Where a soil has formed entirely in one kind of material, a prefix is omitted from the symbol; the whole profile is material 1. Similarly, the uppermost material in a profile having two or more contrasting materials is understood to be material 1, but the number is omitted. Numbering starts with the second layer of contrasting material, which is designated "2." Underlying contrasting layers are numbered consecutively. Even though a layer below material 2 is similar to material 1, it is designated "3" in the sequence. The numbers indicate a change in the material, not the type of material. Where two or more consecutive horizons formed in one kind of material, the same prefix number is applied to all of the horizon designations in that material: Ap-E-Bt1-2Bt2-2Bt3-2BC. The number of suffixes designating subdivisions of the Bt horizon continue in consecutive order across the discontinuity.

If an R layer is below a soil that formed in residuum and the material of the R layer is judged to be like that from which the material of the soil weathered, the Arabic number prefix is not used. If it is thought that the R layer would not produce material like that in the solum, the number prefix is used, as in A-Bt-C-2R or A-Bt-2R. If part of the solum formed in residuum, "R" is given the appropriate prefix: Ap-Bt1-2Bt2-2Bt3-2C1-2C2-2R.

Buried horizons (designated "b") are special problems. A buried horizon is obviously not in the same deposit as horizons in the overlying deposit. Some buried horizons, however, formed in material lithologically like that of the overlying deposit. A prefix is not used to distinguish material of such buried horizons. If the material in which a horizon of a buried soil formed is lithologically unlike that of the overlying material, the discontinuity is designated by number prefixes and the symbol for a buried horizon is used as well: Ap-Bt1-Bt2-BC-C-2ABb-2Btb1-2Btb2-2C.

In organic soils, discontinuities between different kinds of layers are not identified. In most cases, the differences are shown by the letter suffix designations if the different layers are organic or by the master symbol if the different layers are mineral.

Use of the prime.—Identical letter and numerical designations may be appropriate for two or more horizons separated by at least one horizon or layer of a different kind in the same pedon. The sequence A-E-Bt-E-Btx-C is an example: the soil has two E horizons. To make communication easier, the prime is used with the master horizon symbol of the lower of two horizons having identical designations: A-E-Bt-E′-Btx-C. The prime is applied to the capital letter designation and any lower-case symbols follow it: B′t. The prime is not used unless all letters of the designations of two different layers are identical. Rarely, three layers have identical letter symbols; a double prime can be used: E″.

The same principle applies in designating layers of organic soils. The prime is used only to distinguish two or more horizons that have identical symbols: Oi-C-O′i-C′ or Oi-C-Oe-C′. The prime is added to the lower C layer to differentiate it from the upper.

Sample Horizon Sequences

The following examples illustrate some common horizon and layer sequences of important soils and the use of arabic numerals to identify their subdivisions. The examples were selected from soil descriptions on file and modified to reflect present conventions.

Mineral soils:
- Typic Hapludoll: A1-A2-Bw-BC-C
- Typic Haploboroll: Ap-A-Bw-Bk-Bky1-Bky2-C
- Cumulic Haploboroll: Ap-A-Bw1-Bw2-BC-Ab-Bwb1-Bwb2-2C
- Typic Argialboll: Ap-A-E-Bt1-Bt2-BC-C
- Typic Argiaquoll: A-AB-BA-Btg-BCg-Cg
- Entic Haplorthod: Oi-Oa-E-Bs1-Bs2-BC-C
- Typic Haplorthod: Ap-E-Bhs-Bs-BC-C1-C2
- Typic Fragiudalf: Oi-A-E-BE-Bt1-Bt2-B/E-Btx1-Btx2-C
- Typic Haploxeralf: A1-A2-A3-2Bt1-2Bt2-2Bt3-2BC-2C
- Glossoboric Hapludalf: Ap-E-B/E-Bt1-Bt2-C
- Typic Paleudult: A-E-Bt1-Bt2-B/E-B′t1-B′t2-B′t3
- Typic Hapludult: 0i-A1-A2-BA-Bt1-Bt2-BC-C
- Arenic Plinthic Paleudult: Ap-E-Bt-Btc-Btv1-Btv2-BC-C
- Typic Haplargid: A-Bt-Bk1-Bk2-C
- Entic Durorthid: A-Bw-Bq-Bqm-2Ab-2Btkb-3Byb-3Bqmb-3Bqkb
- Typic Dystrochrept: Ap-Bw1-Bw2-C-R
- Typic Fragiochrept: Ap-Bw-E-Bx1-Bx2-C
- Typic Haplaquept: Ap-AB-Bg1-Bg2-BCg-Cg
- Typic Udifluvent: Ap-C-Ab-C′
- Typic Haplustert: Ap-A-AC-C1-C2

Organic soils:
- Typic Medisaprist: Op-Oa1-Oa2-Oa3-C
- Typic Sphagnofibrist: Oi1-Oi2-Oi3-Oe
- Limnic Borofibrist: Oi-C-O′i1-O′i2-C′-Oe-C′
- Lithic Cryofolist: Oi-Oa-R

Cyclic and Intermittent Horizons and Layers

A profile of a soil having cyclic horizons exposes layers whose boundaries are near the surface at one point and extend deep into the soil at another. At one place the aggregate horizon thickness may be only 50 cm; two meters away, the same horizons may be more than 125 cm thick. The cycle is repeated, commonly with considerable variation in both depth and horizontal interval, but still with some degree of regularity. If the soil is visualized in three dimensions instead of two, some cyclic horizons extend downward in inverted cones. The cone of the lower horizon fits around the cone of the horizon above. Other cyclic horizons would appear wedge-shaped.

A profile of a soil having an intermittent horizon shows that the horizon extends horizontally for some distance, ends, and reappears again some distance away. A B horizon interrupted at intervals by upward

extensions of bedrock into the A horizon is an example. The distance between places where the horizon is absent is commonly variable, yet it has some degree of regularity. The distances range from less than one meter to several meters.

Obviously, a soil profile at one place could be unlike a profile only a few meters away for soils with cyclic or intermittent horizons or layers. The order of the variations of these soils are given in soil descriptions.

Descriptions of the order of horizontal variation within a pedon include the kind of variation, the spacing of cycles or interruptions, and the amplitude of depth variation of cyclic horizons.

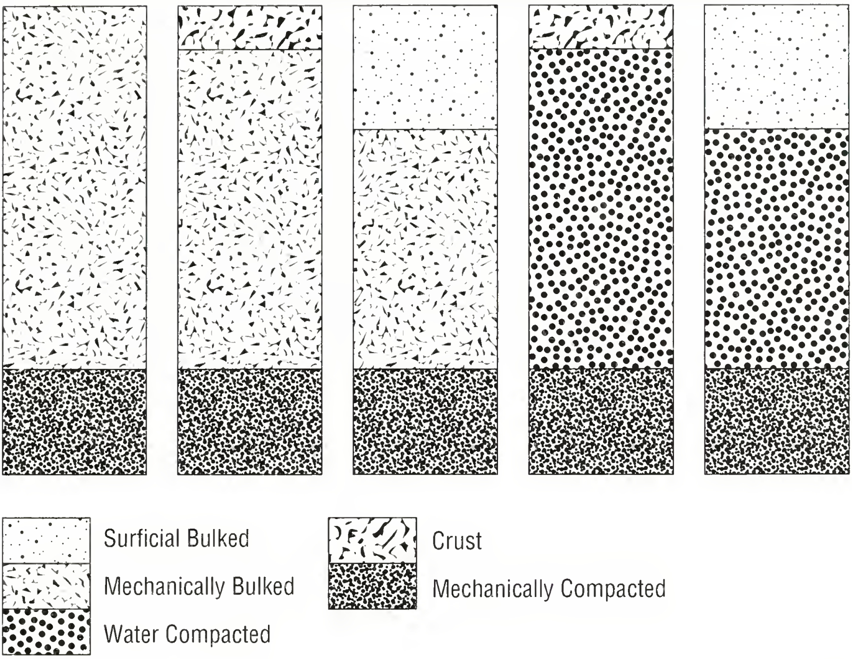
Near Surface Subzones

The morphology of the uppermost few centimeters is subject in many soils to strong control by antecedent weather and by soil use. A soil may be freshly tilled today and have a loose surface. Tomorrow it may have a strong crust because of a heavy rain. Or, in one place soil may be highly compacted by livestock and have a firm near surface even though over most of its extent the same uppermost few centimeters are little disturbed and very friable. There is a need for a set of terms to describe subzones of the near surface and, in particular, the near surface of tilled soils. Five subzones of the near surface are recognized (fig. 3-13).

The *mechanically bulked* subzone has undergone through mechanical manipulation a reduction in bulk density and an increase in discreteness of structural units, if present. Usually the mechanical manipulation is the consequence of tillage operations. Rupture resistance of the mass overall, inclusive of a number of structural units, is *loose* or *very friable* and *occasionally friable*. Individual structural units may be *friable* or even *firm*. Mechanical continuity among structural units is low. Structure grade, if the soil material exhibits structural units < 20 mm across, is moderate or strong. Strain that results from contraction on drying of individual structural units may not extend among structural units. Hence, internally initiated desiccation cracks may be weak or absent even though the soil material in a consolidated condition has considerable potential extensibility. Cracks may be present, however, if they are initiated deeper in the soil.

The *mechanically compacted* subzone has been subject to compaction, usually in tillage operations but possibly by animals. Commonly, mechanical continuity of the fabric and bulk density are increased. Rupture resistance depends on texture and degree of compaction. Generally, *friable* is the minimum class. Mechanical continuity of the fabric permits propagation of strain that results on drying only over several centimeters. Internally initiated cracks appear if the soil material has appreciable extensibility and drying has been sufficient. In some soils this

FIGURE 3-13



Five kinds of near surface subzones. (Scale is approximately 18 cm.)

subzone restricts root growth. The suffix "d" may be used if compaction results in a strong plow pan.

The *water-compacted* subzone has been compacted by repetitive large changes in water state without mechanical load except for the weight of the soil. Repetitive occurrence of free water is particularly conducive to compaction. Depending on texture, moist rupture resistance ranges from *very friable* through *firm*. Structural units, if present, are less discrete than for the same soil material if mechanically bulked. Structure generally would be weak or the condition would be massive. Mechanical continuity of the fabric is sufficient that strain which originates on drying propagates appreciable distances. As a consequence, if extensibility is sufficient, cracks develop on drying. In many soils, over time the water-compacted subzone replaces the mechanically bulked subzone. The replacement can occur in a single year if the subzone is subject to periodic occurrence of free water with intervening periods when *slightly moist* or *dry*. The presence of a water-compacted subzone and the absence of the mechanically bulked subzone is an important consequence of no-till farming systems.

The *surficial bulked* subzone occurs in the very near surface. Continuity of the fabric is low. Cracks are not initiated in this subzone, although they may be present if initiated in underlying more compacted soil. The subzone is formed by various processes. Frost action under conditions where the soil is drier than wet is a mechanism. Wetting and drying of soil material with high extensibility is another origin; certain Vertisols are illustrative.

Crust is a surficial subzone, usually less than 50 mm thick, that exhibits markedly more mechanical continuity of the soil fabric than the zone immediately beneath. Commonly, the original soil fabric has been reconstituted by water action and the original structure has been replaced by a massive condition. While the material is *wet*, raindrop impact and freeze-thaw cycles are mechanisms leading to reconstitution. Crusting related to *raindrop-impact* and *freeze-thaw* are recognized.

A *fluventic* zone may be formed by local transport and deposition of soil material in tilled fields. Such a feature has weaker mechanical continuity than a crust. The rupture resistance is lower, and the reduction in infiltration may be less than for crusts of similar texture. A raindrop-impact crust may occur on a fluventic zone.

Crusts and a fluventic zone may be described in terms of thickness in millimeters, structure and other aspects of the fabric, and by consistence, including rupture resistance while dry and micropenetration resistance while wet. Thickness pertains to the zone where reconstitution of the fabric has been pronounced. Also, the distance between *surface-initiated cracks* may be a useful observation for seedling emergence considerations. If the distance is short, the weight of the crust slabs is low.

Soil material with little apparent reconstitution commonly adheres beneath the crust and is removed with the crust. This soil material that shows little or no reconstitution is not part of the crust and does not contribute to the thickness.

Identification of subzones is not clear cut. Morphological expression of bulking and compaction may be quite different among soils dependent on particle size distribution, organic matter content, clay mineralogy, water regime, and possibly other factors.

The distinction between a bulked and compacted state for soil material with appreciable extensibility is made in part on the potential for the transmission of strain on drying over distances greater than the horizontal dimensions of the larger structural units. In a bulked subzone little or no strain is propagated; in a compacted subzone the strain would be propagated over distances greater than the horizontal dimensions of the larger structural units. Many soils have low extensibility because of texture, clay mineralogy, or both. For these soils, the

expression of cracks cannot be used to distinguish between a bulked and compacted state.

The distinction between compaction and bulking is subjective. It is useful to establish a concept of a normal degree of compaction of the near surface to which the actual degree of compaction is compared. The concept for tilled soils should be the compaction of soil material on level or convex parts of the tillage determined relief. The soil should have been subject to the bulking action of conventional tillage without the subsequent mechanical compaction. The subzone in question should have been brought to a *wet* or *very moist* water state from an appreciably drier condition followed by drying to *slightly moist* or drier at least once. It should not have been subject, however, to a large number of wetting and drying cycles where the maximum wetness involves the presence of free water. If the soil material has a degree of compaction similar to what would be expected, then the term *normal compaction* is employed.

Boundaries of Horizons and Layers

A boundary is a surface or transitional layer between two adjoining horizons or layers. Most boundaries are zones of transition rather than sharp lines of division. Boundaries vary in distinctness and in topography.

Distinctness.—Distinctness refers to the thickness of the zone within which the boundary can be located. The distinctness of a boundary depends partly on the degree of contrast between the adjacent layers and partly on the thickness of the transitional zone between them. Distinctness is defined in terms of thickness of the transitional zone:

Abrupt: Less than 2 cm thick
Clear: 2 to 5 cm thick
Gradual: 5 to 15 cm thick
Diffuse: More than 15 cm thick

Abrupt soil boundaries, such as those between the E and Bt horizons in many soils, are easily determined. Some boundaries are not readily seen but can be located by testing the soil above and below the boundary. Diffuse boundaries, such as those in many old soils in tropical areas, are most difficult to locate and require time-consuming comparisons of small specimens of soil from various parts of the profile until the midpoint of the transitional zone is determined. For soils that have nearly uniform properties or that change very gradually as depth increases, horizon boundaries are imposed more or less arbitrarily without clear evidence of differences.

Topography.—Topography refers to the irregularities of the surface that divides the horizons. Even though soil layers are commonly seen in vertical section, they are three dimensional. Topography of boundaries is described with the following terms:

Smooth:	The boundary is a plane with few or no irregularities.
Wavy:	The boundary has undulations in which depressions are wider then they are deep.
Irregular:	The boundary has pockets that are deeper than they are wide.
Broken:	One or both of the horizons or layers separated by the boundary are discontinuous and the boundary is interrupted.

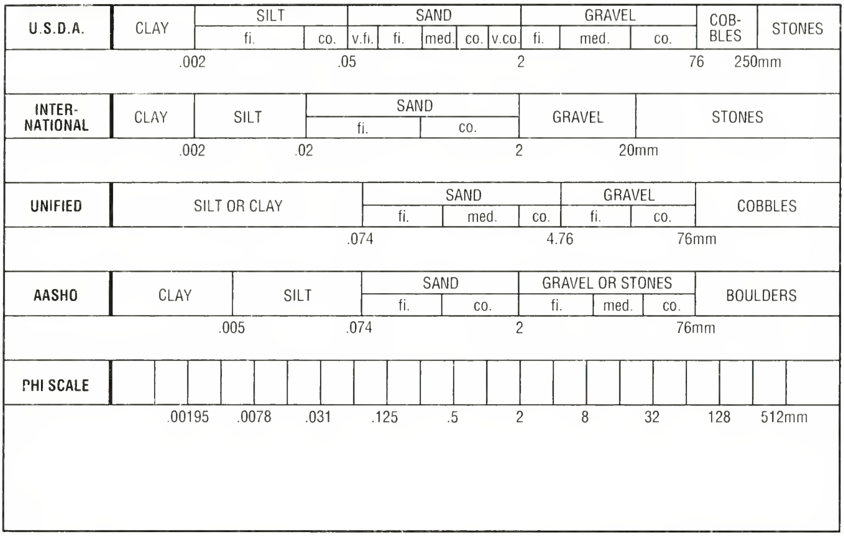
Root Restricting Depth

The root restricting depth is where root penetration would be strongly inhibited because of physical (including soil temperature) and/or chemical characteristics. Restriction means the incapability to support more than a *few fine* or *very fine* roots if depth from the soil surface and water state, other than the occurrence of frozen water, are not limiting. For cotton or soybeans and possibly other crops with less abundant roots than the grasses, the *very few* class is used instead of the *few* class. The restriction may be below where plant roots normally occur because of limitations in water state, temperatures, or depth from the surface. The evaluation should be for the specific plants that are important to the use of the soil. These plants should be indicated. The root-restriction depth may differ depending on the plant considered.

Root-depth observations preferably should be used to make the generalization. If these are not available—and often they are not because roots do not extend to the depth of concern—then inferences may be made from morphology. Some guidelines follow for physical restriction. Chemical restrictions, such as high extractable aluminum and/or low extractable calcium, are not considered here. These are generally not determinable by field examination alone.

Physical root restriction is assumed at contact to rock, whether hard or soft. Further, certain pedogenic horizons, such as *fragipans*, infer root restriction. A change in particle size distribution alone, as for example

FIGURE 3-14



Relationships among particle size classes of 5 different systems.

loamy sand over gravel, is not always a basis for physical root restriction.

A common indication of physical root restriction is a combination of structure and consistence which together suggest that the resistance of the soil fabric to root entry is high and that vertical cracks and planes of weakness for root entry are absent or widely spaced. Root restriction is inferred for a continuously *cemented* zone of any thickness; or a zone >10-cm thick that when *very moist* or *wet* is *massive*, *platy*, or has *weak* structure of any type for a vertical repeat distance of >10 cm and while *very moist* or *wet* is *very firm* (*firm*, if sandy), *extremely firm*, or has a *large* penetration resistance.

Classes of root-restricting depth:

Very shallow:	< 25
Shallow:	25-50 cm
Moderately deep:	50-100 cm
Deep:	100-150 cm
Very deep:	≥ 150 cm

Particle Size Distribution

This section discusses particle distribution. The finer sizes are called *fine earth* (smaller than 2 mm diameter) as distinct from *rock fragments* (pebbles, cobbles, stones, and boulders). Particle-size distribution of fine earth or less than 2 mm is determined in the field mainly by feel. The content of rock fragments is determined by estimating the proportion of the soil volume that they occupy.

Soil Separates

The United States Department of Agriculture uses the following size separates for the <2 mm mineral material:

Very coarse sand:	2.0-1.0 mm
Coarse sand:	1.0-0.5 mm
Medium sand:	0.5-0.25 mm
Fine sand:	0.25-0.10 mm
Very fine sand:	0.10-0.05 mm
Silt:	0.05-0.002 mm
Clay:	< 0.002 mm

Figure 3-14 compares the USDA system with others.

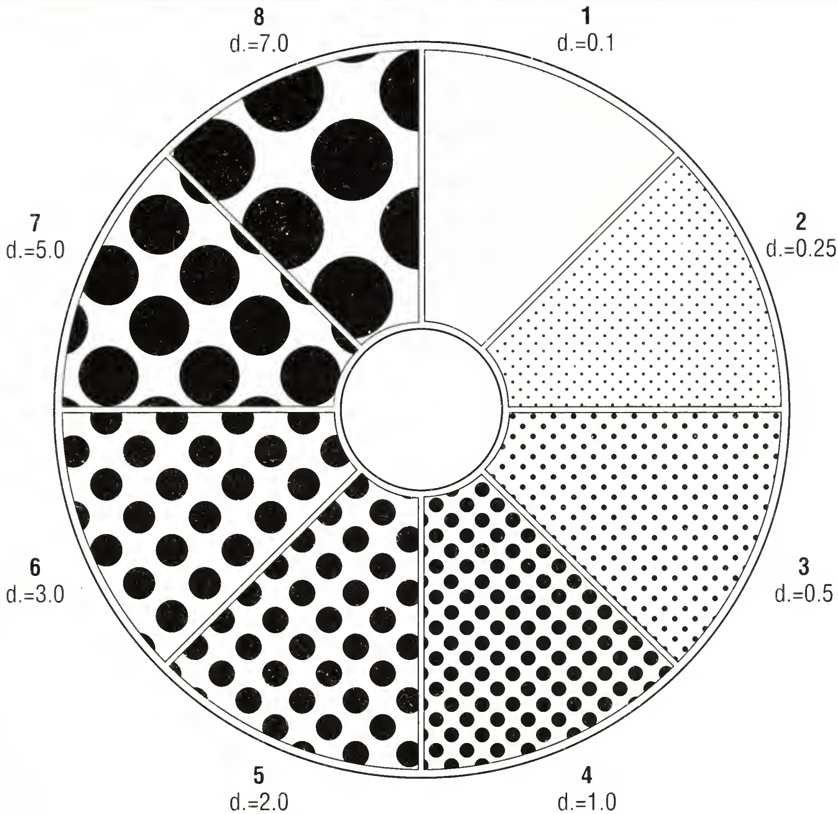
Figure 3-15 illustrates classes of soil particles larger than silt.

Soil Texture

Soil texture refers to the weight proportion of the separates for particles less than 2 mm as determined from a laboratory particle-size distribution. Field estimates should be checked against laboratory determinations and the field criteria should be adjusted as necessary. Some soils are not dispersed completely in the standard particle size analysis. For these, the field texture is referred to as *apparent* because it is not an estimate of the results of a laboratory operation. Apparent field texture is a tactile evaluation only with no inference as to laboratory test results. Field criteria for estimating soil texture must be chosen to fit the soils of the area. Sand particles feel gritty and can be seen individually with the naked eye. Silt particles cannot be seen individually without magnification; they have a smooth feel to the fingers when dry or wet. In some places, clay soils are sticky; in others they are not. Soils dominated by montmorillonite clays, for example, feel different from soils that contain similar amounts of micaceous or kaolintic clay. Even locally, the relationships that are useful for judging texture of one kind of soil may not apply as well to another kind.

The texture classes (fig. 3-16) are sand, loamy sands, sandy loams, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy

FIGURE 3-15



Sizes of particles of indicated diameters (d) in millimeters.

clay, silty clay, and clay. Subclasses of sand are subdivided into coarse sand, sand, fine sand, and very fine sand. Subclasses of loamy sands and sandy loams that are based on sand size are named similarly.

Definitions of the soil texture classes follow:

Sands.—More than 85 percent sand, the percentage of silt plus 1.5 times the percentage of clay is less than 15 .

Coarse sand. A total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sand. A total of 25 percent or more very coarse, coarse, and medium sand, a total of less than 25 percent very coarse and coarse sand, and less than 50 percent fine sand and less than 50 percent very fine sand.

FIGURE 3-16

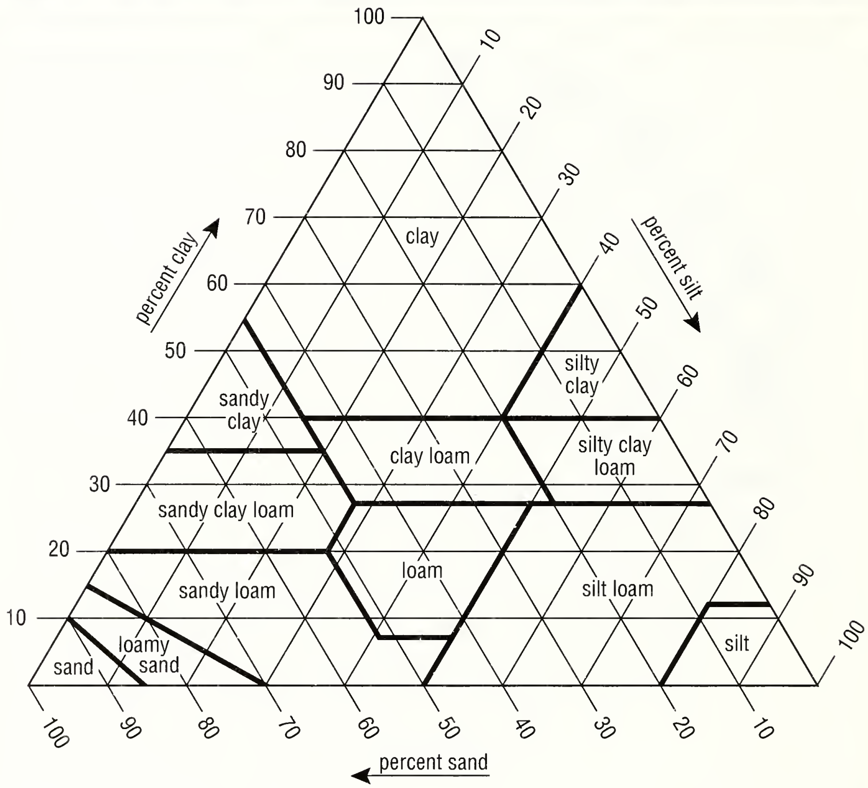


Chart showing the percentages of clay, silt, and sand in the basic textural classes.

Fine sand. 50 percent or more fine sand; or a total of less than 25 percent very coarse, coarse, and medium sand and less than 50 percent very fine sand.

Very fine sand. 50 percent or more very fine sand.

Loamy sands.—Between 70 and 91 percent sand and the percentage of silt plus 1.5 times the percentage of clay is 15 or more; and the percentage of silt plus twice the percentage of clay is less than 30.

Loamy coarse sand. A total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Loamy sand. A total of 25 percent or more very coarse, coarse, and medium sand and a total of less than 25 percent very coarse and

coarse sand, and less than 50 percent fine sand and less than 50 percent very fine sand.

Loamy fine sand. 50 percent or more fine sand; or less than 50 percent very fine sand and a total of less than 25 percent very coarse, coarse, and medium sand.

Loamy very fine sand. 50 percent or more very fine sand.

Sandy loams.—7 to 20 percent clay, more than 52 percent sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or less than 7 percent clay, less than 50 percent silt, and more than 43 percent sand.

Coarse sandy loam. A total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sandy loam. A total of 30 percent or more very coarse, coarse, and medium sand, but a total of less than 25 percent very coarse and coarse sand and less than 30 percent fine sand and less than 30 percent very fine sand; or a total of 15 percent or less very coarse, coarse, and medium sand, less than 30 percent fine sand and less than 30 percent very fine sand with a total of 40 percent or less fine and very fine sand.

Fine sandy loam. 30 percent or more fine sand and less than 30 percent very fine sand; or a total of 15 to 30 percent very coarse, coarse, and medium sand; or a total of more than 40 percent fine and very fine sand, one half or more of which is fine sand, and a total of 15 percent or less very coarse, coarse, and medium sand.

Very fine sandy loam. 30 percent or more very fine sand and a total of less than 15 percent very coarse, coarse, and medium sand; or more than 40 percent fine and very fine sand, more than one half of which is very fine sand, and a total of less than 15 percent very coarse, coarse, and medium sand.

Loam.—7 to 27 percent clay, 28 to 50 percent silt, and 52 percent or less sand.

Silt loam. 50 percent or more silt and 12 to 27 percent clay, or 50 to 80 percent silt and less than 12 percent clay.

Silt. 80 percent or more silt and less than 12 percent clay.

Sandy clay loam. 20 to 35 percent clay, less than 28 percent silt, and more than 45 percent sand.

Clay loam. 27 to 40 percent clay and more than 20 to 46 percent sand.

Silty clay loam. 27 to 40 percent clay and 20 percent or less sand.

Sandy clay. 35 percent or more clay and 45 percent or more sand.

Silty clay. 40 percent or more clay and 40 percent or more silt.

Clay. 40 percent or more clay, 45 percent or less sand, and less than 40 percent silt.

The texture triangle (fig. 3-16) is used to resolve problems related to word definitions, which are somewhat complicated. The eight distinctions in the sand and loamy sand groups provide refinement greater than can be consistently determined by field techniques. Only those distinctions that are significant to use and management and that can be consistently made in the field should be applied.

Groupings of soil texture classes.—The need for fine distinctions in the texture of the soil layers results in a large number of classes of soil texture. Often it is convenient to speak generally of broad groups or classes of texture. An outline of soil texture groups, in three classes and in five, follows. In some areas where soils are high in silt, a fourth general class, silty soils, may be used for silt and silt loam.

General terms [9]	*Texture classes*
Sandy soil materials	
Coarse-textured	Sands (coarse sand, sand, fine sand, very fine sand) Loamy sands (loamy coarse sand, loamy sand, loamy fine sand, loamy very fine sand)
Loamy soil materials:	
Moderately coarse-textured	Coarse sandy loam, sandy loam, fine sandy loam
Medium-textured	Very fine sandy loam, loam, silt loam, silt
Moderately fine-textured	Clay loam, sandy clay loam, silty clay loam
Clayey soils:	
Fine-textured	Sandy clay, silty clay, clay

[9] These are sandy, loamy, and clayey texture groups, not the sandy, loamy, and clayey particle-size classes defined in *Soil Taxonomy*.

Organic Soils

Layers that are not saturated with water for more than a few days at a time are organic if they have 20 percent or more organic carbon. Layers that are saturated for longer periods, or were saturated before being drained, are organic if they have 12 percent or more organic carbon and no clay, 18 percent or more organic carbon and 60 percent or more clay, or a proportional amount of organic carbon, between 12 and 18 percent, if the clay content is between 0 and 60 percent.

The kind and amount of the mineral fraction, the kind of organisms from which the organic material was derived, and the state of decomposition affect the properties of the soil material. Descriptions include the percentage of undecomposed fibers and the solubility in sodium pyrophosphate of the humified material. A special effort is made to identify and estimate the volume occupied by *sphagnum* fibers, which have extraordinary high water retention characteristics. When squeezed firmly in the hand to remove as much water as possible, *sphagnum* fibers are lighter in color than fibers of *hypnum* and most other mosses.

Fragments of wood more than 2 cm across and so undecomposed that they cannot be crushed by the fingers when moist or wet are called "wood fragments." They are comparable to rock fragments in mineral soils and are described in a comparable manner.

Muck (sapric) is well-decomposed, organic soil material. Peat (fibric) is relatively undecomposed, organic material in which the original fibers constitute almost all of the material. *Mucky peat* (hemic) is material intermediate between muck and peat.

Rock Fragments

Rock fragments are unattached pieces of rock 2 mm in diameter or larger that are *strongly cemented* or more resistant to rupture. Rock fragments include all sizes that have horizontal dimensions less than the size of a pedon.

Rock fragments are described by size, shape, and, for some, the kind of rock. The classes are *pebbles*, *cobbles*, *channers*, *flagstones*, *stones*, and *boulders* (table 3-11). If a size or range of sizes predominates, the class is modified, as for example: "fine pebbles," "cobbles 100 to 150 mm in diameter," "channers 25 to 50 mm in length."

Gravel is a collection of pebbles that have diameters ranging from 2 to 75 mm. The term is applied to the collection of pebbles in a soil layer with no implication of geological formalization. The terms "pebble" and "cobble" are usually restricted to rounded or subrounded fragments; however, they can be used to describe angular fragments if they are not flat. Words like chert, limestone, and shale refer to a kind of rock, not a

piece of rock. The composition of the fragments can be given: "chert pebbles," "limestone channers." The upper size of gravel is 3 inches (75 mm). This coincides with the upper limit used by many engineers for grain-size distribution computations. The 5-mm and 20-mm divisions for the separation of fine, medium, and coarse gravel coincide with the sizes of openings in the "number 4" screen (4.76 mm) and the "3/4 inch" screen (19.05 mm) used in engineering.

The 75 mm (3 inch) limit separates gravel from cobbles. The 250-mm (10-inch) limit separates cobbles from stones, and the 600-mm (24-inch) limit separates stones from boulders. The 150-mm (channers) and 380 mm (flagstones) limits for thin, flat fragments follow conventions used for many years to provide class limits for plate-shaped and crudely spherical rock fragments that have about the same soil use implications as the 250-mm limit for spherical shapes.

Rock Fragments in the Soil

Historically, the total volume of rock fragments of all sizes has been used to form classes. The interpretations program imposes requirements that cannot be met by grouping all sizes of rock fragments together. Furthermore, the interpretations program requires weight rather than volume estimates. For interpretations, the weight percent >250, 75-250, 5-75 and 2-5 mm are required; the first two are on a whole soil basis, and the latter two are on a <75 mm basis. For the >250 and 75-250 mm, weighing is generally impracticable. Volume percentage estimates would be made from areal percentage measurements by point-count or line-intersect methods. Length of the transect or area of the exposure should be 50 and preferably 100 times the area or dimensions of the rock fragment size that encompasses about 90 percent of the rock fragment volume. For the <75 mm weight, measurements are feasible but may require 50-60 kg of sample if appreciable rock fragments near 75 mm are present. An alternative is to obtain volume estimates for the 20-75 mm and weight estimates for the <20 mm. This is favored because of the difficulty in visual evaluation of the 2 to 5 mm size separations. The weight percentages of 5-20 and 2-5 mm may be converted to volume estimates and placed on a <75 mm base by computation. The adjectival form of a class name of rock fragments (table 3-11) is used as a modifier of the textural class name: "gravelly loam," "stony loam." The following classes, based on volume percentages, are used:

> *Less than 15 percent*: No adjectival or modifying terms are used in writing for contrast with soils having less than 15 percent pebbles, cobbles, or flagstones. The adjective "slightly" may be used, however, to recognize those soils used for special purposes.

TABLE 3-11

Terms for rock fragments.

Shape[1] and size	Noun	Adjective
Spherical, cubelike, or equiaxial:		
2-75 mm diameter	Pebbles	Gravelly
2-5 mm diameter	Fine	Fine gravelly
5-20 mm diameter	Medium	Medium gravelly
20-75 mm diameter	Coarse	Coarse gravelly
75-250 mm diameter	Cobbles	Cobbly
250-600 mm diameter	Stones	Stony
≥600 mm diameter	Boulders	Bouldery
Flat:		
2-150 mm long	Channers	Channery
150-380 mm long	Flagstones	Flaggy
380-600 mm long	Stones	Stony
≥600 mm long	Boulders	Bouldery

[1]The roundness of the fragments may be indicated as angular (strongly developed faces with sharp edges), irregular (prominent flat faces with incipient rounding of corners), subrounded (detectable flat faces with well-rounded corners), and rounded (flat faces absent or nearly absent with all corners

15 to 35 percent: The adjectival term of the dominant kind of rock fragment is used as a modifier of the textural term: "gravelly loam," "channery loam," "cobbly loam" (fig. 3-17).

35 to 60 percent: The adjectival term of the dominant kind of rock fragment is used with the word "very" as a modifier of the textural term: "very gravelly loam," "very flaggy loam" (fig. 3-18).

More than 60 percent: If enough fine earth is present to determine the textural class (approximately 10 percent or more by volume) the adjectival term of the dominant kind of rock fragment is used with the word "extremely" as a modifier of the textural term: "extremely gravelly loam," "extremely bouldery loam." If there is too little fine earth to determine the textural class (less than about 10 percent by volume) the term "gravel," "cobbles," "stones," or "boulders" is used as appropriate.

The class limits apply to the volume of the layer occupied by all pieces of rock larger than 2 mm. The soil generally contains fragments smaller or larger than those identified in the term. For example, a stony loam usually contains pebbles, but "gravelly" is not mentioned in the name. The use of a term for larger pieces of rock, such as boulders, does not imply that the pieces are entirely within a given soil layer. A single boulder may extend through several layers.

More precise estimates of the amounts of rock fragments than are provided by the defined classes are needed for some purposes. If the more precise information is needed, estimates of percentages of each size class or a combination of size classes are included in the description: "very cobbly loam; 30 percent cobbles and 15 percent gravel" or "silt loam; about 10 percent gravel."If loose pieces of rock are significant in use and management of a soil, they are the basis of phase distinctions among map units. Exposed bedrock is not soil and is separately identified in mapping.

The volume occupied by individual pieces of rock can be seen and their aggregate volume percentage can be calculated. For some purposes, volume percentage must be converted to weight percentage.

FIGURE 3-17

A soil with cobbly horizon. Both angular cobbles and angular pebbles are present, but the cobbles dominate in the limitations they impose. Rock fragments occupy about 25 percent by volume of the plowed layer.

FIGURE 3-18

A soil with a very cobbly surface horizon. Rock fragments occupy about 40 percent of the plowed layer and are concentrated on the surface.

Rock Fragments at the Surface

The treatment of gravel, cobbles and channers (2-250 mm) differs from that for stones and boulders (>250 mm).[10] The reason for the difference is that an important aspect of the description of the 2-250 mm is the areal percent cover on the ground surface afforded by the rock fragments. For the >250 mm, the percent of cover is not of itself as important as the interference with mechanical manipulation of the soil. A very small areal percentage of large rock fragments, insignificant for erosion protection, may interfere with tillage.

The areal percentage over the ground surface is determined using point-count and/or line-intersect procedures. If the areal percentage exceeds 80 percent, the top of the soil is the mean height of the top of the rock fragments. The volume proportions of 2 to 5 mm, 5 to 75 mm, and 75 to 250 mm should be recorded. This can be done from areal measurements.

The number, size, and spacing of stones and boulders (>250 mm) on the surface of a soil, including both those that lie on the surface and those that are partly within the soil but protrude above ground, have important effects on soil use and management. The class limits that follow are given in terms of the approximate amount of stones and boulders at the surface.

[10]These terms are defined in table 3-11.

Class 1. Stones or boulders cover about 0.01 to 0.1 percent of the surface. Stones of the smallest sizes are at least 8 m apart; boulders of the smallest sizes are at least 20 m apart (fig. 3-19).

Class 2. Stones or boulders cover about 0.1 to 3 percent of the surface. Stones of the smallest sizes are not less than 1 m apart; boulders of the smallest size are no less than 3 m apart

Class 3. Stones or boulders cover about 3 to 15 percent of the surface. Stones of the smallest size are as little as 0.5 m apart; boulders of the smallest size are as little as 1 m apart (fig. 3-21).

Class 4. Stones or boulders cover about 15 to 50 percent of the surface. Stones of the smallest size are as little as 0.3 m apart; boulders of the smallest size are as little as 0.5 m apart. In most places it is possible to step from stone to stone or jump from boulder to boulder without touching the soil (fig. 3-22).

Class 5. Stones or boulders appear to be nearly continuous and cover 50 to 90 percent of the surface. Stones of the smallest size are less than 0.03 m apart; boulders of the smallest size are less than 0.05 m apart. Classifiable soil is among the rock fragments, and plants can grow if not otherwise limited (fig. 3-23).

These limits are intended only as guides to amounts that may mark critical limitations for major kinds of land use. Table 3-12 is a summary of the classes.

Soil Color

Elements of soil color descriptions are the color name, the Munsell notation, the water state, and the physical state: "brown (10YR 5/3), dry, crushed, and smoothed."

Physical state is recorded as broken, rubbed, crushed, or crushed and smoothed. The term "crushed" usually applies to dry samples and "rubbed" to moist samples. If unspecified, the surface is broken. The color of the soil is recorded for a surface broken through a ped if a ped can be broken as a unit.

The color value of most soil material becomes lower after moistening. Consequently, the water state of a sample is always given. The water state is either "moist" or "dry." The dry state for color determinations is air-dry and should be made at the point where the color does not change

FIGURE 3-19

An area of a bouldery soil (class 1).

FIGURE 3-20

An area of a very bouldery soil (class 2).

FIGURE 3-21

An area of an extremely bouldery soil (class 3).

FIGURE 3-22

An area of a rubbly soil (class 4).

with additional drying. Color in the moist state is determined on moderately moist or very moist soil material and should be made at the point where the color does not change with additional moistening. The soil should not be moistened to the extent that glistening takes place as color determinations of wet soil may be in error because of the light reflection of water films. In a humid region, the moist state generally is considered standard; in an arid region, the dry state is standard. In detailed descriptions, colors of both dry and moist soil are recorded if feasible. The color for the regionally standard moisture state is usually described first. Both moist and dry colors are particularly valuable for the immediate surface and tilled horizons in order to assess reflectance.

Munsell notation is obtained by comparison with a Munsell system color chart. The most commonly used chart includes only about one fifth of the entire range of hues.[11] It consists of about 250 different colored

[11]The appropriate color chips, separate or mounted by hue on special cards for a loose-leaf notebook, may be obtained from the Munsell Company.

FIGURE 3-23

An area of a very rubbly soil (class 5).

TABLE 3-12

Classes of surface stones and boulders in terms of cover and spacing.

Class	Percentage of surface covered	Distance in meters between stones or boulders if the diameter is 0.25m[1]	0.6 m	1.2 m	Name
1	0.01-0.1	≥8	≥20	≥37	Stony or bouldery
2	0.1-3.0	1-8	3-20	6-37	Very stony or very bouldery
3	3.0-15	0.5-1	1-3	2-6	Extremely stony or extremely bouldery
4	15-50	0.3-0.5	0.5-1	1-2	Rubbly
5	50-90	<0.3	<0.5	<1	Very Rubbly

[1]0.38 m if flat

papers, or chips, systematically arranged on hue cards according to their Munsell notations. Figure 3-24 illustrates the arrangements of color chips on a Munsell color card.

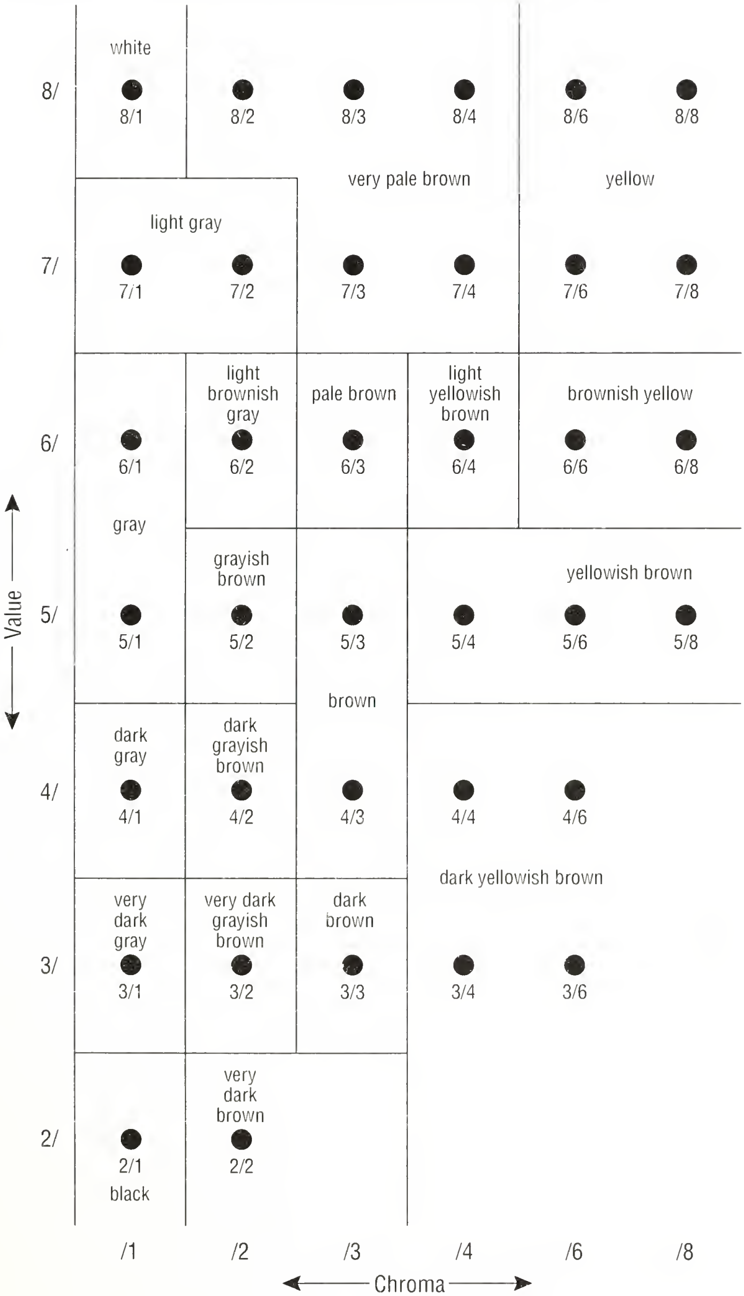
The Munsell color system uses three elements of color—*hue*, *value*, and *chroma*—to make up a color notation. The notation is recorded in the form: hue, value/chroma—for example, 5Y 6/3.

Hue is a measure of the chromatic composition of light that reaches the eye. The Munsell system is based on five principal hues: red (R), yellow (Y), green (G), blue (B), and purple (P). Five intermediate hues representing midpoints between each pair of principal hues complete the 10 major hue names used to describe the notation. The intermediate hues are yellow-red (YR), green-yellow (GY), blue-green (BG), purple-blue (PB), and red-purple (RP). The relationships among the 10 hues are shown in figure 3-25. Each of the 10 major hues is divided into four segments of equal visual steps, which are designated by numerical values applied as prefixes to the symbol for the hue name.[12] In figure 3-25, for example, 10R marks a limit of red hue. Four equally spaced steps of the adjacent yellow-

[12]The notation for hue, and for value and chroma, is decimal and could be refined to any degree. In practice, however, only the divisions on the color charts are used.

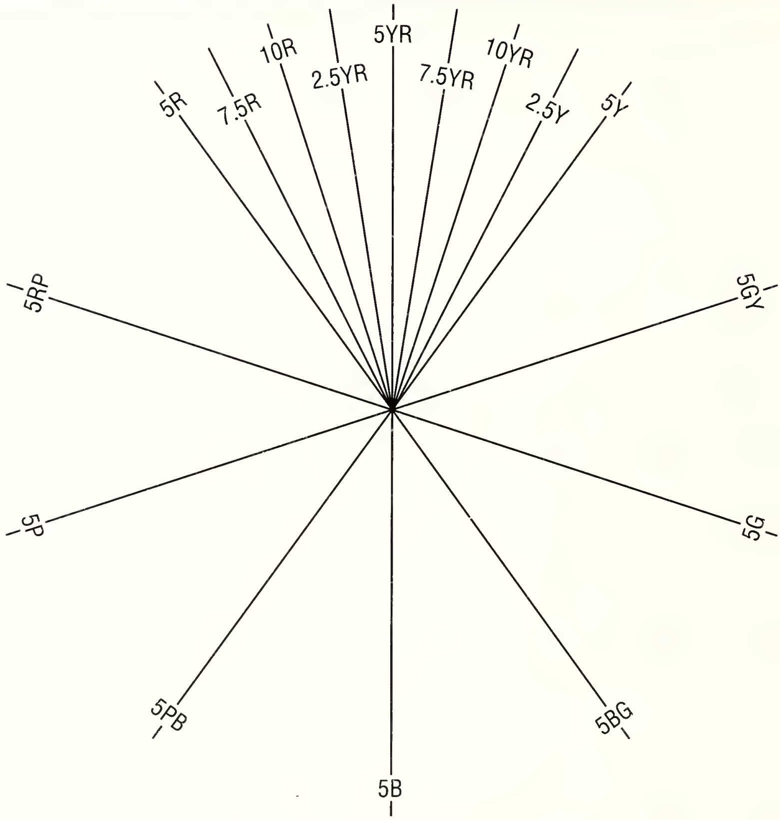
FIGURE 3-24

Soil Color Names of Hue 10YR



The arrangement of color chips according to value and chroma on the soil-color card of 10YR hue.

FIGURE 3-25



A schematic diagram of relationships among the five principal and five intermediate hues of the Munsell Color System and subdivisions within the part used for most soil colors.

red (YR) hue are identified as 2.5YR, 5YR, 7.5YR, and 10YR respectively. The standard chart for soil has separate hue cards from 10R through 5Y.

Value indicates the degree of lightness or darkness of a color in relation to a neutral gray scale. On a neutral gray (achromatic) scale, value extends from pure black (0/) to pure white (10/). The value notation is a measure of the amount of light that reaches the eye under standard lighting conditions. Gray is perceived as about halfway between black and white and has a value notation of 5/. The actual amount of light that reaches the eye is related logarithmically to color value. Lighter colors are indicated by numbers between 5/ and 10/; darker colors are indicated by numbers from 5/ to 0/. These values may be designated for either achromatic or chromatic conditions. Thus, a card of the color chart for soil has a series of chips arranged vertically to show equal steps from the lightest to

the darkest shades of that hue. Figure 3-24 shows this arrangement vertically on the card for the hue of 10YR.

Chroma is the relative purity or strength of the spectral color. Chroma indicates the degree of saturation of neutral gray by the spectral color. The scales of chroma for soils extend from /0 for neutral colors to a chroma of /8 as the strongest expression of color used for soils. Figure 3-24 illustrates that color chips are arranged horizontally by increasing chroma from left to right on the color card.

The complete color notation can be visualized from figure 3-24. Pale brown, for example, is designated 10YR 6/3. Very dark brown is designated 10YR 2/2. All of the colors on the chart have hue of 10YR. The darkest shades of that hue are at the bottom of the card and the lightest shades are at the top. The weakest expression of chroma (the grayest color) is at the left; the strongest expression of chroma is at the right.

At the extreme left of the card are symbols such as N 6/. These are colors of zero chroma which are totally achromatic—neutral color. They have no hue and no chroma but range in value from black (N 2/) to white (N 8/). An example of a notation for a neutral (achromatic) color is N 5/ (gray). The color 10YR 5/1 is also called "gray," for the hue is hardly perceptible at such low chroma.

Conditions for measuring color.—The quality and intensity of the light affect the amount and quality of the light reflected from the sample to the eye. The moisture content of the sample and the roughness of its surface affect the light reflected. The visual impression of color from the standard color chips is accurate only under standard conditions of light intensity and quality. Color determination may be inaccurate early in the morning or late in the evening. When the sun is low in the sky or the atmosphere is smoky, the light reaching the sample and the light reflected is redder. Even though the same kind of light reaches the color standard and the sample, the reading of sample color at these times is commonly one or more intervals of hue redder than at midday. Colors also appear different in the subdued light of a cloudy day than in bright sunlight. If artificial light is used, as for color determinations in an office, the light source used must be as near the white light of midday as possible. With practice, compensation can be made for the differences unless the light is so subdued that the distinctions between color chips are not apparent. The intensity of incidental light is especially critical when matching soil to chips of low chroma and low value.

Roughness of the reflecting surface affects the amount of reflected light, especially if the incidental light falls at an acute angle. The incidental light should be as nearly as possible at a right angle. For crushed samples, the surface is smoothed; the state is recorded as "dry, crushed, and smoothed."

Recording Guidelines

Uncertainty.—Under field conditions, measurements of color are reproducible by different individuals within 2.5 units of hue (one card) and 1 unit of value and chroma. Notations are made to the nearest whole unit of value and chroma.

Before 1989, the cards for hues of 2.5YR, 7.5YR, and 2.5Y did not include chips for colors having chroma of 3. These colors are encountered frequently in some soils and can be estimated reliably by interpolation between adjacent chips of the same hue. Chips for chromas of 5 and 7 are not provided on any of the standard color cards. Determinations are usually not precise enough to justify interpolation between chromas of 4 and 6 or 6 and 8. Color should never be extrapolated beyond the highest chip. It should also be rounded to the nearest chip.

For many purposes, the differences between colors of some adjacent color chips have little significance. For such purposes, color notations have been grouped, and the groups have been named (fig. 3-24).

Dominant Color

The dominant color is the color that occupies the greatest volume of the layer. Dominant color (or colors) is always given first among those of a multicolored layer. It is judged on the basis of colors of a broken sample. For only two colors, the dominant color makes up more than 50 percent of the volume. For three or more colors, the dominant color makes up more of the volume of the layer than any other color, although it may occupy less than 50 percent. The expression "brown with yellowish brown and grayish brown" signifies that brown is the dominant color. It may or may not make up more than 50 percent of the layer.

In some layers, no single color is dominant and the first color listed is not more prevalent than others. The expression "brown and yellowish brown with grayish brown" indicates that brown and yellowish brown are about equal and are codominant. If the colors are described as "brown, yellowish brown, and grayish brown," the three colors make up nearly equal parts of the layer.

Mottling

Mottling refers to repetitive color changes that cannot be associated with compositional properties of the soil. Redoximorphic features are a type of mottling that is associated with wetness. A color pattern that can be related to proximity to a ped surface or other organizational or compositional feature is not mottling. Mottle description follows the dominant

color. Mottles are described by quantity, size, contrast, color, and other attributes in that order.

Quantity is indicated by three areal percentage classes of the observed surface:

few:	less than 2 percent,
common:	2 to 20 percent, and
many:	more than 20 percent.

The notations must clearly indicate to which colors the terms for quantity apply. For example, "common grayish brown and yellowish brown mottles" could mean that each makes up 2 to 20 percent of the horizon. By convention, the example is interpreted to mean that the quantity of the two colors *together* is between 2 and 20 percent. If each color makes up between 2 and 20 percent, the description should read "common grayish brown (10YR 5/2) and common yellowish brown (10YR 5/4) mottles."

Size refers to dimensions as seen on a plane surface. If the length of a mottle is not more than two or three times the width, the dimension recorded is the greater of the two. If the mottle is long and narrow, as a band of color at the periphery of a ped, the dimension recorded is the smaller of the two and the shape and location are also described. Three size classes are used:

fine:	smaller than 5 mm,
medium:	5 to 15 mm, and
coarse:	larger than 15 mm.

Contrast refers to the degree of visual distinction that is evident between associated colors:

Faint: Evident only on close examination. Faint mottles commonly have the same hue as the color to which they are compared and differ by no more than 1 unit of chroma or 2 units of value. Some faint mottles of similar but low chroma and value differ by 2.5 units (one card) of hue.

Distinct: Readily seen but contrast only moderately with the color to which they are compared. Distinct mottles commonly have the same hue as the color to which they are compared but differ by 2 to 4 units of chroma or 3 to 4 units of value; or differ from the color to which they are compared by 2.5 units (one card) of hue but by no more than 1 unit of chroma or 2 units of value.

Prominent: Contrast strongly with the color to which they are compared. Prominent mottles are commonly the most obvious color feature of the section described. Prominent mottles that have medium chroma and value commonly differ from the color to which they are compared by at least 5 units (two pages) of hue if chroma and value are the same; at least 4 units of value or chroma if the hue is the same; or at least 1 unit of chroma or 2 units of value if hue differs by 2.5 units (one card).

Contrast is often not a simple comparison of one color with another but is a visual impression of the prominence of one color against a background commonly involving several colors.

Shape, location, and character of boundaries of mottles are indicated as needed. *Shape* is described by common words such as streaks, bands, tongues, tubes, and spots. *Location* of mottles as related to structure of the soil may be significant. *Boundaries* may be described as *sharp* (color gradation is not discernable with the naked eye), *clear* (color grades over less than 2 mm), or *diffuse* (color grades over more than 2 mm).

Moisture state and physical state of the dominant color are presumed to apply to the mottles unless the description states otherwise. An example, for which a standard moist broken state of the sample has been specified, might read "brown (10YR 4/3), brown (10YR 5/3) dry; many medium distinct yellowish brown (10YR 5/6) mottles, brownish yellow (10YR 6/6) dry." Alternatively, the colors in the standard moisture state may be given together, followed by the colors at other moisture states. The color of mottles commonly is given only for the standard state unless special significance can be attached to colors at another state.

A nearly equal mixture of two colors for a moist broken standard state can be written "intermingled brown (10YR 4/3) and yellowish brown (10YR 5/6) in a medium distinct pattern; brown (10YR 5/3) and brownish yellow (10YR 6/6) dry." If a third color is present, "common medium faint dark grayish brown (10YR 4/2) mottles, grayish brown (10YR 5/2) dry" can be added.

If the mottles are fine and faint so that they cannot be compared easily with the color standards, the Munsell notation should be omitted. Other abbreviated descriptions are used for specific circumstances.

Color Patterns

Color, including mottling, may be described separately for any feature that may merit a separate description, such as peds, concretions, nodules, cemented bodies, filled animal burrows, and the like. Color patterns that exhibit a spatial relationship to composition changes or to features such as

nodules or surfaces of structural units may be useful to record because of the inferences that may be drawn about genesis and soil behavior. Colors may be given for extensions of material from another soil layer. The fine tubular color patterns that extend vertically below the A horizon of some wet soils, for example, were determined by the environment adjacent to roots that once occupied the tubules. The rim of bright color within an outer layer of lighter color at the surface of some peds relate to water movement into and out of the peds and to oxidation-reduction relationships.

Ground surface color.—The color value of the immediate ground surface may differ markedly from that of the surface horizon. For example, raindrop impact may have removed clay-size material from the surface of sand and silt which results in a surficial millimeter or so of increased color value. In some arid soils, dark rock fragments may have reduced the color value of the ground surface appreciably from that of the fine earth of the surface horizon as a whole. Furthermore, dead vegetation may have color values that differ appreciably from those for the fine earth of the surface horizon. Color information is, therefore, desirable for the actual ground surface inclusive of the vegetation as well as the soil material. Surface color influences reflectivity of light, therefore, the capacity to absorb and release radiant energy.

Surface soil colors commonly range widely at a site, and it may be necessary to array mentally the color values and their areal proportion for the ground surface, whether rock fragments, dead vegetation, or fine earth. Then a single color value is selected for each important ground surface component. From the areal proportion of the components, and their color value, a weighted average color value for the ground surface may be computed. Estimation of the areal proportion of components is discussed in the section on ground cover.

Soil Structure

Soil structure refers to units composed of primary particles. The cohesion within these units is greater than the adhesion among units. As a consequence, under stress, the soil mass tends to rupture along predetermined planes or zones. These planes or zones, in turn, form the boundary. Compositional differences of the fabric matrix appear to exert weak or no control over where the bounding surfaces occur. If compositional differences control the bounding surfaces of the body, then the term "concentration" is employed. The term "structural unit" is used for any repetitive soil body that is commonly bounded by planes or zones of weakness that are not an apparent consequence of compositional differences. A structural unit that is the consequence of soil development is called a *ped*. The

surfaces of peds persist through cycles of wetting and drying in place. Commonly, the surface of the ped and its interior differ as to composition or organization, or both, because of soil development. Earthy *clods* and *fragments* stand in contrast to peds, for which soil forming processes exert weak or no control on the boundaries. Some clods, adjacent to the surface of the body, exhibit some rearrangement of primary particles to a denser configuration through mechanical means. The same terms and criteria used to describe structured soils should be used to describe the shape, grade, and size of clods. Structure is not inferred by using the terms interchangeably. A size sufficient to affect tilth adversely must be considered. The distinction between clods and fragments rests on the degree of consolidation by mechanical means. Soil fragments include (1) units of undisturbed soil with bounding planes of weakness that are formed on drying without application of external force and which do not appear to have predetermined bounding planes, (2) units of soil disturbed by mechanical means but without significant rearrangement to a denser configuration, and (3) pieces of soil bounded by planes of weakness caused by pressure exerted during examination with size and shape highly dependent on the manner of manipulation.

Some soils lack structure and are referred to as *structureless*. In structureless layers or horizons, no units are observable in place or after the soil has been gently disturbed, such as by tapping a spade containing a slice of soil against a hard surface or dropping a large fragment on the ground. When structureless soils are ruptured, soil fragments, single grains, or both result. Structureless soil material may be either single grain or massive. Soil material of single grains lacks structure. In addition, it is loose. On rupture, more than 50 percent of the mass consists of discrete mineral particles.

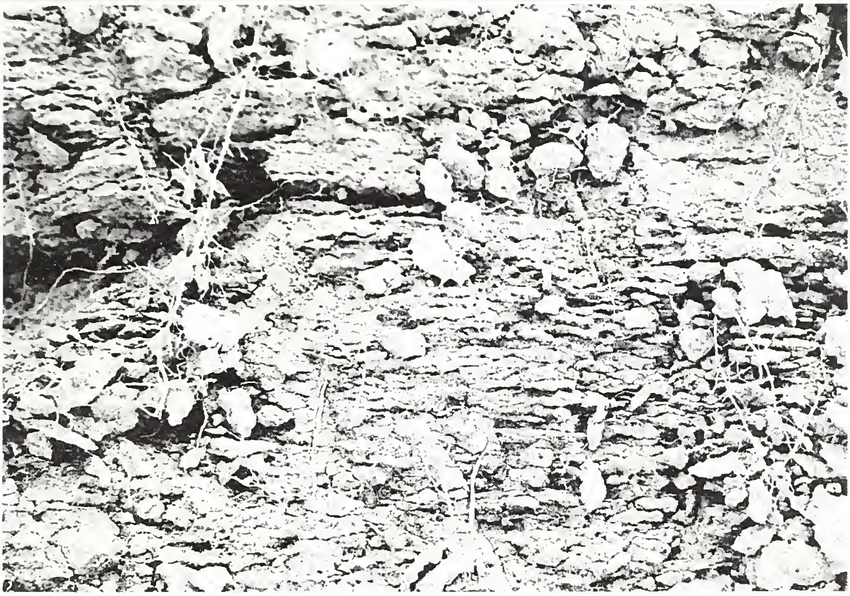
Some soils have *simple structure*, each unit being an entity without component smaller units. Others have *compound structure*, in which large units are composed of smaller units separated by persistent planes of weakness.

In soils that have structure, the shape, size, and grade (distinctness) of the units are described. Field terminology for soil structure consists of separate sets of terms designating each of the three properties, which by combination form the names for structure.

Shape.—Several basic shapes of structural units are recognized in soils. Supplemental statements about the variations in shape of individual peds are needed in detailed descriptions of some soils. The following terms describe the basic shapes and related arrangements:

platy: The units are flat and platelike. They are generally oriented horizontally. Platy structure is illustrated in figure 3-26. A special form,

FIGURE 3-26



Strong thin platy structure.

FIGURE 3-27

Strong medium prismatic structure. The prisms are 35 to 45 mm across.

lenticular platy structure, is recognized for plates that are thickest in the middle and thin toward the edges.

prismatic: The individual units are bounded by flat to rounded vertical faces. Units are distinctly longer vertically, and the faces are typically casts or molds of adjoining units. Vertices are angular or subrounded; the tops of the prisms are somewhat indistinct and normally flat. Prismatic structure is illustrated in figure 3-27.

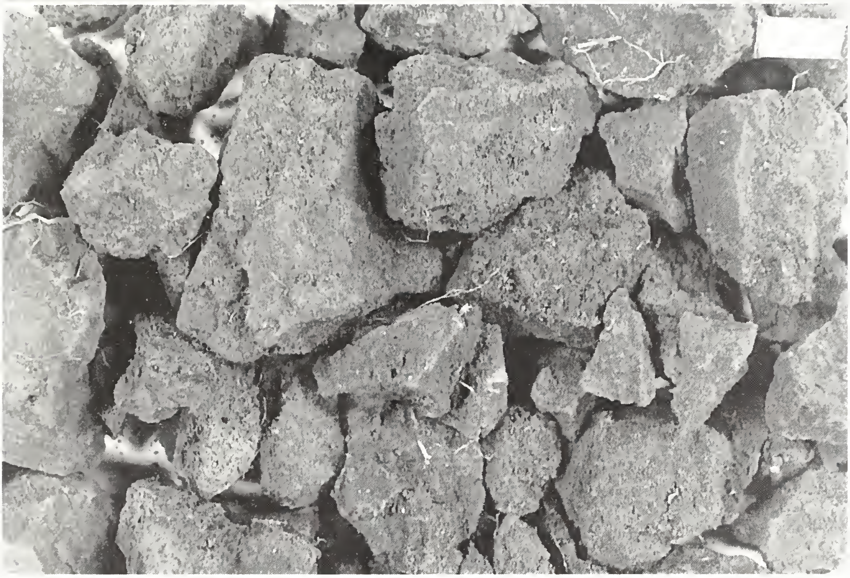
columnar: The units are similar to prisms and are bounded by flat or slightly rounded vertical faces. The tops of columns, in contrast to those of prisms, are very distinct and normally rounded, as illustrated in figure 3-28.

blocky: The units are blocklike or polyhedral. They are bounded by flat or slightly rounded surfaces that are casts of the faces of surrounding peds. Typically, blocky structural units are nearly equidimensional but grade to prisms and to plates. The structure is described as *angular blocky* if the faces intersect at relatively sharp angles; as *subangular blocky* if the faces are a mixture of rounded and plane faces and the corners are mostly rounded. Figure 3-29 illustrates angular blocky units.

FIGURE 3-28

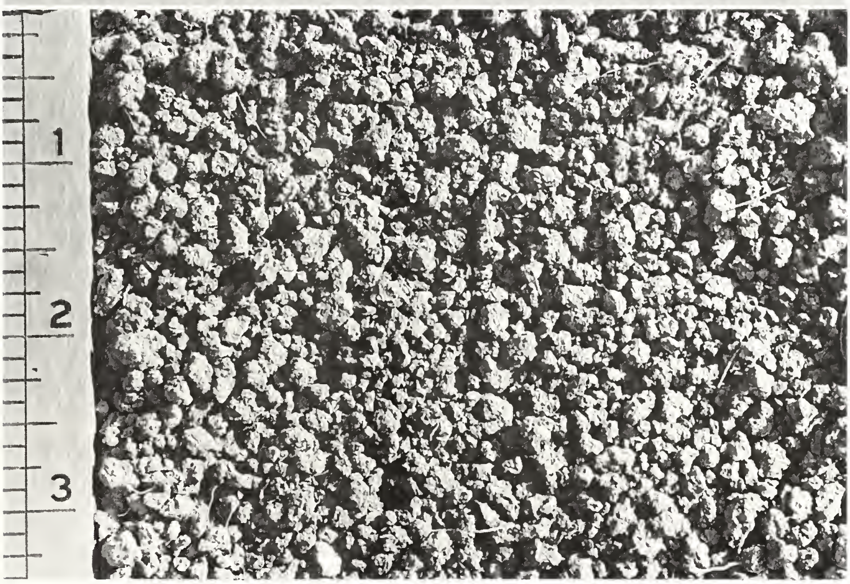
A cluster of strong medium columnar pads. The cluster is about 135 mm across.

FIGURE 3-29



Strong medium and coarse blocky peds.

FIGURE 3-30



Strong fine and medium granular peds.

TABLE 3-13

Size classes of soil structure.

	Shape of structure			
Size Classes	***Platy*** [1] mm	***Prismatic and Columnar*** mm	***Blocky*** mm	***Granular*** mm
Very fine	<1	<10	<5	<1
Fine	1-2	10-20	5-10	1-2
Medium	2-5	20-50	10-20	2-5
Coarse	5-10	50-100	20-50	5-10
Very coarse	>10	>100	>50	>10

[1]In describing plates, "thin" is used instead of "fine" and "thick" instead of "coarse."

granular: The units are approximately spherical or polyhedral and are bounded by curved or very irregular faces that are not casts of adjoining peds. Granular units are illustrated in figure 3-30.

Size.—Five classes are employed: very fine, fine, medium, coarse, and very coarse. The size limits of the classes differ according to the shape of the units. The size limit classes are given in table 3-13. The size limits refer to the smallest dimension of plates, prisms, and columns. If the units are more than twice the minimum size of "very coarse," the actual size is given: "prisms 30 to 40 cm across."

Grade.—Grade describes the distinctness of units. Criteria are the ease of separation into discrete units and the proportion of units that hold together when the soil is handled. Three classes are used:

Weak. The units are barely observable in place. When gently disturbed, the soil material parts into a mixture of whole and broken units and much material that exhibits no planes of weakness. Faces that indicate persistence through wet-dry-wet cycles are evident if the soil is handled carefully. Distinguishing structurelessness from

weak structure is sometimes difficult. Weakly expressed structural units in virtually all soil materials have surfaces that differ in some way from the interiors.

Moderate. The units are well formed and evident in undisturbed soil. When disturbed, the soil material parts into a mixture of mostly whole units, some broken units, and material that is not in units. Peds part from adjoining peds to reveal nearly entire faces that have properties distinct from those of fractured surfaces.

Strong. The units are distinct in undisturbed soil. They separate cleanly when the soil is disturbed. When removed, the soil material separates mainly into whole units. Peds have distinctive surface properties.

The distinctness of individual structural units and the relationship of cohesion within units to adhesion between units determine grade of structure. Cohesion alone is not specified. For example, individual structural units in a sandy loam A horizon may have strong structure, yet they may be less durable than individual units in a silty clay loam B horizon of weak structure. The degree of disturbance required to determine structure grade depends largely on moisture content and percentage and kind of clay. Only slight disturbance may be necessary to separate the units of a moist sandy loam having strong granular structure, while considerable disturbance may be required to separate units of a moist clay loam having strong blocky structure.

The three terms for soil structure are combined in the order (1) grade, (2) size, (3) shape. "Strong fine granular structure" is used to describe a soil that separates almost entirely into discrete units that are loosely packed, roughly spherical, and mostly between 1 and 2 mm in diameter.

The designation of structure by grade, size, and shape can be modified with other appropriate terms when necessary to describe other characteristics. Surface characteristics of units are described separately. Special structural units, such as the wedge-shaped units of Vertisols, are described in appropriate terms.

Compound Structure

Smaller structural units may be held together to form larger units. Grade, size, and shape are given for both and the relationship of one set to the other is indicated: "strong medium blocks within moderate coarse prisms," or "moderate coarse prismatic structure parting to strong medium blocky."

Extra-Structural Cracks

Cracks are macroscopic vertical planar voids with a width much smaller than length and depth. A crack represents the release of strain that is a consequence of drying. In many soils, cracks bound individual structural units. These cracks are repetitive and usually quite narrow. Their presence is part of the concept of the structure. The cracks to be discussed are the result of localized stress release which forms planar voids that are wider than the repetitive planar voids between structural units or which occur in massive or weakly structured material at relatively wide intervals. These cracks may be coextensive with crack space between structural units. If they are coextensive, the width exceeds that of the associated structural cracks. The areal percentage of such cracks, either on a vertical exposure or on the ground surface, may be measured by line-intercept methods. For taxonomic purposes, the width and depth of cracks has importance. Four kinds of extra-structural cracks may be recognized:

> *Surface-initiated reversible cracks* form as a result of drying from the surface downward. They close after relatively slight surficial wetting and have little influence on ponded infiltration rates.
>
> *Surface-initiated irreversible cracks* form on near-surface water reduction from exceptionally high water content related to freeze-thaw action and other processes. The cracks do not close completely when rewet and extend through the crust formed by frost action. They act to increase ponded infiltration rates.
>
> *Subsurface-initiated reversible cracks* form as a result of appreciable reduction in water content from "field capacity" in horizons or layers with considerable extensibility. They close in a matter of days if the horizon is brought to the *moderately moist* or wetter state. They extend upward to the soil surface unless there is a relatively thick overlying horizon that is very weakly compacted (loose or very friable) and does not permit the propagation of cracks (mechanically bulked subzones (fig. 3-13, for example). Such cracks importantly influence ponded infiltration rates and evaporation directly from the soil.
>
> *Subsurface-initiated irreversible cracks* are the "permanent" cracks of the USDA soil taxonomy system (see figure 3-31). They have a similar origin to surface-initiated irreversible cracks, although quite different agencies are involved.

FIGURE 3-31

Natural fragments formed by cracking of a massive soil as it contracted upon drying.

The foregoing genetic definition of cracks does not directly relate to prediction of infiltration. For such predictions, the surface connectiveness of the cracks and their depth must be specified. *Surface-connected cracks* occur at the ground surface or are covered by up to 10-15 cm of soil material that would permit the accumulation of free water at the plane that marks the top of the crack under conditions that may occur in most years. If the antecedent water state of the overlying zone were *very moist*, free water from 25 mm of rainfall in one hour should reach the top of the cracks. Usually the zone would have *very high* or *high* saturated hydraulic conductivity. Such subzones may exhibit structure or be single grain. The structure units range widely in size. The common characteristic is that the consistent units of the mass as a whole are highly discrete and the porosity of the interstices among the structural units is high. If not too thick, the *mechanically bulked* subzone of tilled surface horizons would be such a zone.

A crack depth index value may be obtained by insertion of a blunt wire, approximately 2 mm in diameter.[13] *Penetrant cracks* are 15 cm or

[13]Crack depth by wire insertion may yield considerably shallower depths than is measured by pouring loose sand into the crack and excavating after wetting and the crack has closed. The latter method, however, is only suitable for detailed examination; whereas, wire insertion is relatively rapid and can be completed in a single observation.

more in depth as measured by wire insertion. Cracks that are both *penetrant* and *surface connected* are described as *penetrant surface connected*. Penetrant surface-connected cracks act to increase transient ponded infiltration. Prominence of the penetrant surface-connected cracks would depend on the linear distance of such cracks per unit area of ground surface. The linear distance may be allowed to decrease as crack depths increase. No classes are provided.

Internal Surface Features

Surface features include (1) coats of a variety of substances unlike the adjacent soil material and covering part or all of surfaces, (2) material concentrated on surfaces by the removal of other material, and (3) stress formations in which thin layers at the surfaces have undergone reorientation or packing by stress or shear. All differ from the adjacent material in composition, orientation, or packing.

Descriptions of surface features may include kind, location, amount, continuity, distinctness, and thickness of the features. In addition, color, texture, and other characteristics that apply may be described, especially if they contrast with the characteristics of the adjacent material.

Kinds.—Surface features are distinguished by differences in texture, color, packing, orientation of particles, or reaction to various tests. If a feature is distinctly different from the adjacent material but kind cannot be determined, it is still described.

> *Clay films* (synonymous with *clay skins*) are thin layers of oriented, translocated clay.
>
> *Clay bridges* link together adjacent mineral grains.
>
> *Sand* or *silt coats* are sand or silt grains adhering to a surface. Some sand and silt coats are concentrations of the sand and silt originally in the horizon from which finer particles have been removed. Some sand and silt coats are material that has been moved from horizons above and deposited on surfaces. In some coats the grains are almost free of finer material; in others, the grains themselves are coated. If known, the composition of the coat is noted.
>
> *Other coats* are described by properties that can be observed in the field. The coats are composed variously of iron, aluminum or manganese oxides, organic matter, salts, or carbonates. Laboratory analyses may be needed for a positive identification.

FIGURE 3-32

Intersecting slickensides in the Bss horizon of a Udic Haplustert. The cracking is due to drying after exposure.

Stress surfaces (pressure faces) are smoothed or smeared surfaces. They are formed through rearrangement as a result of shear forces. They may persist through successive drying and wetting cycles.

Slickensides (fig. 3-32) are stress surfaces that are polished and striated and usually have dimensions exceeding 5 cm. They are produced by relatively large volumes of soil sliding over another. They are common below 50 cm in swelling clays which are subject to large changes in water state.

Location.—The various surface features may be on some or all structural units, channels, pores, primary particles or grains, soil fragments, rock fragments, nodules, or concretions. The kind and orientation of surface on which features are observed is always given. For example, if clay films are on vertical but not horizontal faces of peds, this fact should be recorded.

Amount.—The percentage of the total surface area of the kind of surface considered occupied by a particular surface feature over the extent of the horizon or layer is described. Amount can be characterized by the following classes:

very few:	Occupies < 5 percent.
few:	Occupies 5 to 25 percent.
common:	Occupies 25 to 50 percent.
many:	Occupies ≥ 50 percent.

The same classes are used to describe the amount of "bridges" connecting particles. The amount is judged on the basis of the percentage of particles of the size designated that are joined to adjacent particles of similar size by bridges at contact points.

Distinctness.—Distinctness refers to the ease and degree of certainty with which a surface feature can be identified. Distinctness is related to thickness, color contrast with the adjacent material, and other properties. It is, however, not itself a measure of any one of them. Some thick coats, for example, are faint; some thin ones are prominent. The distinctness of some surface features changes markedly as water state changes. Three classes are used.

Faint. Evident only on close examination with 10X magnification and cannot be identified positively in all places without greater magnification. The contrast with the adjacent material in color, texture, and other properties is small.

Distinct. Can be detected without magnification, although magnification or tests may be needed for positive identification. The feature contrasts enough with the adjacent material to make a difference in color, texture, or other properties evident.

Prominent. Conspicuous without magnification when compared with a surface broken through the soil. Color, texture, or some other property or combination of properties contrasts sharply with properties of the adjacent material or the feature is thick enough to be conspicuous.

The order of description is usually amount, distinctness, color, texture, kind, and location. Two examples: "few distinct grayish brown (10YR 5/2) clay films on vertical faces of peds"; "many distinct brown clay bridges between mineral grains." Only properties are listed that add to the understanding of the soil. If texture of the surface feature is obvious, as in most stress surfaces, repeating texture adds nothing. Kind and location are essential if the feature is mentioned at all. The conventions do not characterize the volume of the surface features. If volume is important, it is estimated separately.

Concentrations

The features discussed here are identifiable bodies within the soil that were formed by pedogenesis. Some of these bodies are thin and sheetlike; some are nearly equidimensional; others have irregular shapes. They may contrast sharply with the surrounding material in strength, composition, or internal organization. Alternatively, the differences from the surrounding material may be slight. Soft rock fragments which have rock structure but are *weakly cemented* or *noncemented* are not considered concentrations. They are excluded on the basis of inference as to a geological as opposed to a pedological origin.

Masses are noncemented concentrations of substances that commonly cannot be removed from the soil as a discrete unit. Most accumulations consist of calcium carbonate, fine crystals of gypsum or more soluble salts, or iron and manganese oxides. Except for very unusual conditions, *masses* have formed in place.

Plinthite consists of reddish, iron-enriched bodies that are low in organic matter and are coherent enough to be separated readily from the surrounding soil. Plinthite commonly occurs within and above reticulately mottled horizons. Plinthite has higher penetration resistance than adjacent brown or gray bodies or than red bodies that do not harden. Soil layers that contain plinthite rarely become dry in the natural setting. The

FIGURE 3-33

Nodules and concretions: an unbroken nodule at the left, a broken concretion at the right, a hollow nodule in the middle.

bodies are commonly about 5 to 20 mm across their smallest dimension. Plinthite bodies are *firm* or *very firm* when moist, *hard* or *very hard* when air dry, and become *moderately cemented* on repetitive wetting and drying. They occur as discrete nodules or plates. The plates are oriented horizontally. The nodules occur above and the plates within the upperpart of the reticulately mottled horizon. The plates generally have a uniformly reddish color and have sharp boundaries with the surrounding brown or gray material. The part of the iron-rich body that is not plinthite normally stains the fingers when rubbed while wet, but the plinthite center does not. It has a harsh, dry feel when rubbed, even if wet. Horizons containing plinthite are more difficult to penetrate with an auger than adjacent horizons at the same water state and clay content but which do not contain plinthite. Plinthite generally becomes less cemented after prolonged submergence in water. An air dry sample can be dispersed by normal procedures for particle-size distribution.

Nodules and *concretions* are cemented bodies that can be removed from the soil intact. Composition ranges from material dominantly like that of the surrounding soil to nearly pure chemical substances entirely different from the surrounding material. Their form is apparently not governed by crystal forms based on examination at a magnification of 10X as is the case for crystals and clusters of crystals. It is impossible to be sure if some certain nodules and concretions formed where they are observed or were transported.

Concretions are distinguished from nodules on the basis of internal organization. Concretions have crude internal symmetry organized around a point, a line, or a plane. Nodules lack evident, orderly, internal organization. A typical example of a concretion organized around a point is illustrated in figure 3-33. The internal structure typically takes the form of concentric layers that are clearly visible to the naked eye. A coat or a very thin outer layer of an otherwise undifferentiated body does not indicate a concretion.

Crystals are considered to have been formed in place. They may occur singly or in clusters. Crystals of gypsum, calcite, halite, and other pure compounds are common in some soils. These are described as crystals or clusters of crystals, and their composition is given if known.

Ironstone is an in-place concentration of iron oxides that is at least *weakly cemented*. Ironstone nodules are commonly found in layers above plinthite. These ironstone nodules are apparently plinthite that has cemented irreversibly as a result of repeated wetting and drying. Commonly, the center of iron-rich bodies cements upon repeated wetting and drying but the periphery does not.

Describing Concentrations Within the Soil

Any of a large number of attributes of concentrations within the soil may be important; the most common are number or amount, size, shape, consistence, color composition, kind, and location. Not all of these attributes are necessarily described. The order as listed above is convenient for describing them, as for example: "many, fine, irregular, hard, light gray, carbonate nodules distributed uniformly through the horizon." The conventions for describing kind have been indicated in this section. Descriptions of consistence and color are discussed in other parts of this chapter.

Amount or *quantity* of concentrations refers to the relative volume of a horizon or other specified unit occupied by the bodies. The classes used for quantity of mottles are also used for these features.

Size may be measured directly or given by the classes listed below. The dimension to which size-class limits apply depends on the shape of the body described. If the body is nearly uniform, size is measured in the shortest dimension, such as the effective diameter of a cylinder or the thickness of a plate. For irregular bodies, size refers to the longest dimension unless that creates an erroneous impression; measurements can be given if needed. The following size classes are used:

fine	< 2 mm
medium	2- 5 mm
coarse	5- 20 mm
very coarse	20- 76 mm
extremely coarse	> 76 mm

Shape of concentrations is variable both among kinds of concentrations and commonly within a concentration. The following terms are suggested:

rounded: Approximately equidimensional, a few sharp corners, and at least approximately regular.

cylindrical: At least crudely cylindrical or tubular; one dimension is much greater than the other two.

platelike: Shaped crudely like a plate; one dimension is very much smaller than the other two. The term "platelike" is used to avoid confusion with platy structure.

irregular: Characterized by branching, convoluted, or mycelial form.

The terms listed apply to all concentrations. Individual crystals of a particular mineral usually implies a shape.

Composition of bodies is described if known and if important for understanding their nature or the nature of the soil in which they are observed. Some of the physical attributes of the interior of a feature are implied by the name. Other features, such as enclosed mineral grains, patterns of voids, or similarity to the surrounding soil, may be important.

A distinction is made between bodies that are composed dominantly of a single substance and those that are composed of earthy material impregnated by various substances. For many bodies, the chemical composition cannot be determined with certainty in the field. The following set of terms, however, is useful for describing composition.

If the substance dominates the body, then the body is described as a substance body. If the substance impregnates other material, the body is described as a body of substance accumulation.

Carbonates and iron are common substances that dominate or impregnate nodular or concretionary bodies. Discrete nodules of clay are found in some soils; argillaceous impregnations are less common. Materials dominated by manganese are rare, but manganese is conspicuous in some nodules that are high in iron and mistakenly called "manganese nodules."

Consistence

Soil consistence in the general sense refers to "attributes of soil material as expressed in degree of cohesion and adhesion or in resistance to deformation on rupture." As employed here consistence includes: (1) resistance of soil material to rupture, (2) resistance to penetration, (3) plasticity, toughness, and stickiness of puddled soil material, and (4) the manner in which the soil material behaves when subject to compression. Although several tests are described, only those should be applied which may be useful.

A word may be in order about the similar term, consistency. Consistency was used originally in soil engineering for a set of classes of resistance to penetration by thumb or thumbnail (test designation D 2488, ASTM, 1984). The term has been generalized to cover about the same concept as "consistence." The set of tests specified, however, is different from those given here.

Consistence is highly dependent on the soil-water state and the description has little meaning unless the water state class is specified or is implied by the test. Previously class sets were given for "dry" and "moist" consistence of the soil material as observed in the field. "Wet"

consistence was evaluated for puddled soil material. Here the terms used for "moist" consistence previously are applied to the *wet* state as well. The previous term "wet consistence" is dropped. Stickiness, plasticity, and toughness of the puddled soil material are independent tests.

For determinations on the natural fabric, variability among specimens is likely to be large. Multiple measurements may be necessary. Recording of median values is suggested in order to reduce the influence of the extremes measured.

Rupture Resistance Blocklike Specimens

Table 3-14 contains the classes of resistance to rupture and the means of determination for specimens that are block-like. Different class sets are provided for moderately dry and very dry soil material, and for slightly dry and wetter soil material. Unless specified otherwise, the soil-water state is assumed to be that indicated for the horizon or layer when described. Cementation is an exception. To test for cementation, the specimen is air-dried and then submerged in water for at least 1 hour. The placements do not pertain to the soil material at the field water state.

The blocklike specimen should be 25-30 mm on edge. Direction of stress relative to the in-place axis of the specimen is not defined unless otherwise indicated. The specimen is compressed between extended thumb and forefinger, between both hands, or between the foot and a nonresilent flat surface. If the specimen resists rupture by compression, a weight is dropped onto it from increasingly greater heights until rupture. Failure is at the initial detection of deformation or rupture. Stress applied in the hand should be over a 1-second period. The tactile sense of the class limits may be learned by applying force to top loading scales and sensing the pressure through the tips of the fingers or through the ball of the foot. Postal scales may be used for the resistance range that is testable with the fingers. A bathroom scale may be used for the higher rupture resistance.

Specimens of standard size and shape are not always available. Blocks of specimens that are smaller than 25-30 mm on edge may be tested. The force withstood may be assumed to decrease as the reciprocal of the dimension along which the stress is applied. If a block specimen with a length of 10 mm along the direction the force is applied were to be ruptured, the force should be one-third that for an identical specimen 30 mm on edge. If the specimen is smaller than the standard size, the evaluated rupture resistance should be recorded and the dimensions of the specimen along the axis the stress is applied should be indicated.

Soil structure complicates the evaluation of rupture resistance. If a specimen of standard size can be obtained, report the rupture resistance

TABLE 3-14

Rupture Resistance Classes for Blocklike Specimens.

Classes			Test Description	
Moderately dry and very dry	*Slightly dry and wetter*	*Air dried, submerged*	*Operation*	*Stress Applied a/*
Loose	Loose	Not applicable	Specimen not obtainable	
Soft	Very friable	Noncemented	Fails under very slight force applied slowly between thumb and forefinger	< 8N
Slightly hard	Friable	Extremely weakly cemented	Fails under slight force applied slowly between thumb and forefinger	8- 20N
Moderately hard	Firm	Very weakly cemented	Fails under moderate force applied slowly between thumb and forefinger	20- 40N
Hard	Very firm	Weakly cemented	Fails under strong force applied slowly between thumb and forefinger (80N about maximum force can be applied)	40- 80N
Very hard	Extremely firm	Moderately cemented	Cannot be failed between thumb and forefinger but can be between both hands or by placing on a nonresilent surface and applying gentle force underfoot.	80- 160N

TABLE 3-14 (continued)

Rupture Resistance Classes for Blocklike Specimens.

Classes			Test Description	
Moderately dry and very dry	*Slightly dry and wetter*	*Air dried, submerged*	*Operation*	*Stress Applied a/*
Extremely hard	Slightly rigid	Strongly cemented	Cannot be failed in hands but can be underfoot by full body weight (ca 800N) applied slowly.	160- 800N
Rigid	Rigid	Very strongly cemented	Cannot be failed underfoot by full body weight but can be by < 3J blow.	800N- 3J
Very rigid	Very rigid	Indurated	Cannot be failed by blow of < 3J.	≥ 3J

[a/] Both force (newtons, N) and energy (joules, J) are employed. The number of newtons is 10 times the kilograms of force. One joule is the energy delivered by dropping a 1 kg weight 10 cm.

of the standard specimen and other individual constituent structural units as desired. Usually the constituent structural units must exceed about 5 mm in the direction the stress is applied; expression must exceed weak for the rupture resistance to be evaluated.

If structure size and expression are such that a specimen of standard size cannot be obtained, then the soil material overall is loose. Structural unit resistance to rupture may be determined if the size is large enough (exceed about 5 mm in the direction stress is applied) for a test to be performed.

Rupture Resistance Plate-Shaped Specimens

Tests are described that are applicable to plate-shaped specimens where the length and width are several times more than the thickness. Test procedures were developed for surface crusts but are applicable to plate-shaped bodies at greater depth in the soil. An alternative method of directly measuring plate-shaped specimens is to break them into a crudely blocked form. If the dimensions of the resulting block specimens

TABLE 3-15

Rupture resistance classes applied to crushing plate-shaped specimens

Classes	Force N
Fragile	< 3
Extremely weak	Not removable
Very weak	Removable; < 1
Weak	1-3
Medial	3-20
Moderate	3-8
Moderately strong	8-20
Resistive	≥ 20
Strong	20-40
Very strong	40-80
Extremely strong	≥ 80

are smaller than 25-30 mm on edge, it would be assumed that the measured rupture resistance is lower by 25.

Rupture Resistance by Crushing.—This test was designed primarily for air dry surface crust, but it may be used for other soil features. The morphological description of surface crust is discussed earlier in this chapter. The specimen should be 10 to 15 mm on edge and 5 mm thick or the thickness of occurrence if less than 5 mm. If surface crust, the thickness is inclusive of the crust proper and the adhering soil material beneath. The specimens are small to make the test applicable to crusts with closely spaced cracks. The specimen is grasped on edge between extended thumb and first finger. Force is applied along the longer of the two principal dimensions. Table 3-15 contains a set of classes. Compression to failure should be over about one second. A scale may be used to both rupture the specimens directly and develop the finger tactile sense. Force is applied with the first finger through a bar 5 mm across on the scale to create a similar bearing area to that of the plate-like specimen. The specimen is compressed between thumb and first finger while simultaneously exerting the same felt pressure on the scale with the first finger of the other hand. The scale is read at the failure of the specimen. For specimens that cannot be broken between thumb and forefinger, the resistance to rupture may be evaluated using a small

penetrometer. The specimen is formed with the two larger surfaces parallel and flat. The specimen is placed with a larger face downward on a nonresilient surface and force is applied through the 6 mm diameter penetrometer tip until rupture occurs.

For plate-shaped bodies that are durable enough to withstand handling, such as fragments of fissile sedimentary rock, a modulus of rupture estimation is an appropriate test (Reeve, 1965). In practice, modulus of rupture tests commonly would be used to acquire a tactile sense which then would be used directly in the field. Insufficient experience has been obtained to provide classes.

The tests to follow are hand-held tests. The configuration of the tests do not conform rigorously to the requirements for measurement of modulus of rupture. Furthermore, the amount of force applied may be only roughly approximated. For these reasons, the test results are only a crude measure of the modulus of rupture.

In one test, a specimen is held in contact with a small diameter cylindrical shaft (pencil, nail, and so on) placed near the center of the specimen. Stress is applied by pressing in opposite directions with the two first fingers and the thumbs until rupture occurs. The equation for the modulus of rupture in MPa is:

$$S = \frac{0.15\ FL}{bd^2}$$

where F is the force in newtons, L is the distance between the shaft and the inside edge of the area over which the force is applied on either side of the shaft with the fingers, b is the width of the specimen (in centimeters), and d is the depth or thickness in the direction of the load (in centimeters). The force application is based on the tactile sense and hence is approximate.

In the other approach, the specimen is grasped firmly at one end with pliers and force is applied downward at an established distance (to the nearest 1 cm) from the edge of the pliers. The area over which the force is applied should be small. The flat-end rod penetrometer described in the section on micropenetration resistance works well. A chisel point may be mounted over the tip. Modulus of rupture, S, expressed in megapascals (MPa), is calculated by:

$$S = \frac{0.6FL}{bd^2}$$

where F is the force in newtons, L is the distance between the end of the jaws of the pliers and the inside edge of the area where the force is applied, b is width, and d is the thickness. The dimensions are all in cen-

TABLE 3-16

Plasticity Classes

Classes	Test Description
Non-plastic	A roll 4 cm long and 6 mm thick that supports its own weight held on end cannot be formed.
Slightly plastic	A roll 4 cm long and 6 mm thick can be formed and, if held on end, will support its own weight. A roll 4 mm thick will not support its own weight.
Moderately plastic	A roll 4 cm long and 4 mm thick can be formed and will support its own weight, but a roll 2 mm thick will not support its own weight.
Very plastic	A roll 4 cm long and 2 mm thick can be formed and will support its own weight.

timeters. Length and width are estimated to 1 cm and thickness to 1 mm.

Plasticity

Plasticity (table 3-16) is the degree to which puddled soil material is permanently deformed without rupturing by force applied continuously in any direction. Plasticity is determined on material smaller than 2 mm.

The determination is made on thoroughly puddled soil material at a water content where maximum plasticity is expressed. This water content is above the plastic limit, but it is less than the water content at which maximum stickiness is expressed. The water content is adjusted by adding water or removing it during hand manipulation. The closely related plastic limit that is used in engineering classifications is the water content for < 0.4 mm material at which a roll of 3 mm in diameter which had been formed at a higher water content breaks apart (method D 4318 in ASTM, 1984).

Toughness

Toughness is related to plasticity. Table 3-17 contains a set of classes. The classes are based on the relative force necessary to form with the fingers a roll 3 mm in diameter of < 2 mm soil material at a water content near the plastic limit (test D 2488 in ASTM, 1984).

TABLE 3-17

Toughness Classes

Classes	Criteria
Low	Can reduce the specimen diameter at or near the plastic limit to 3 mm by exertion of < 8N.
Medium	Requires 8-20 N to reduce the specimen diameter at or near the plastic limit to 3 mm.
High	Requires > 20 N to reduce the specimen diameter at or near the plastic limit to 3 mm.

TABLE 3-18

Stickiness Classes

Classes	Test Description
Non-sticky	After release of pressure, practically no soil material adheres to thumb or forefinger.
Slightly sticky	After release of pressure, soil material adheres perceptibly to both digits. As the digits are separated, the material tends to come off one or the other rather cleanly. The material does not stretch appreciably on separation of the digits.
Moderately sticky	After release of pressure, soil material adheres to both digits and tends to stretch slightly rather than pull completely free from either digit.
Very sticky	After release of pressure, soil material adheres so strongly to both digits that it stretches decidedly when the digits are separated. Soil material remains on both digits.

Stickiness

Stickiness refers to the capacity of a soil to adhere to other objects. Table 3-18 contains a set of classes. The determination is made on puddled <2 mm soil material at the water content at which the material is most sticky. The sample is crushed in the hand; water is applied while manip-

ulation is continued between thumb and forefinger until maximum stickiness is reached.

Manner of Failure

The manner in which specimens fail under increasing force ranges widely and usually is highly dependent on water state. To evaluate the manner of failure, a roughly cubical specimen 25-30 mm on edge is pressed between extended forefinger and thumb and/or a handful of soil material is squeezed in the hand. Table 3-19 contains sets of classes and related operations. Some soil materials although wet are brittle; some may be compressed markedly without cracks appearing; others, if wet, behave like liquids; and still others smear if stressed under shear to failure.

Soil in the *slightly moist* or *dry states*, if coherent, is nearly always brittle and probably would not exhibit smeariness; consequently, manner of failure is probably only useful for *moderately moist* or wetter soil material.

Penetration Resistance

Penetration resistance is the capacity of the soil in its confined state to resist penetration by a rigid object. Shape and size of the penetrating object must be defined. Penetration resistance depends strongly on the water state, which should be specified.

The classes in table 3-20 pertain to the pressure required to push the flat end of a cylindrical rod with a diameter of 6.4 mm a distance of 6.4 mm into the soil in about 1 second (Bradford, 1986). Orientation of the axis of insertion should be specified. A correction should be made for the weight of the penetrometer if the axis of insertion is vertical and the resistance is small. If rock fragments are present, the lower values measured are probably more descriptive of the fine earth fabric.

A standard instrument is the pocket penetrometer shown in Bradford (1986). Penetrometers with the same 6.4-mm diameter flat end tip and a dial reading device are available. The resistance can be read with less variability using the dial device. The scale on the barrel of the pocket penetrometers should be converted to units of force. The supplied scale on such instruments commonly is based on a regression between penetration resistance and unconfined, compressive strength measurements and has no application in the context here. Penetration resistance is expressed in units of pressure. The preferred unit is the megapascal; the symbol is MPa. For the 6.4-mm diameter tip, the measured force in kilograms is multiplied by 0.31 to obtain the pressure in megapascals. To extend the range of the instrument, weaker and stronger springs may be substituted. Values in megapascals obtained with any diameter of flat-end rod are used to enter the set of classes in table 3-20. Cone-shaped tips

TABLE 3-19

Manner of Failure Classes

Classes	Operation	Test Description Characteristics
Brittle	Gradually increasing compressive pressure applied to a 25-30 mm specimen held between extended thumb and forefinger.	Specimen retains its size and shape (no deformation) until it ruptures abruptly into subunits or fragments.
Semideformable	Same.	Deformation occurs prior to rupture. Cracks develop and specimen ruptures before compression to half its original thickness.
Deformable*	Same.	Specimen can be compressed to half its original thickness without rupture. Radial cracks may appear and extend inward less than half the radius normal to compression.
Nonfluid	A handful of soil material is squeezed in the hand.	None flows through the fingers after exerting full compression.
Slightly fluid*	Same.	After exerting full compression, some flows through the fingers, but most remains in the palm of the hand.
Moderately fluid*	Same.	After exerting full pressure, most flows through the fingers; a small residue remains in the palm of the hand.
Very fluid*	Same.	Under very gentle pressure most flows through the fingers like a slightly viscous fluid; very little or no residue remains.

TABLE 3-19 (continued)

Classes	Operation	Test Description Characteristics
Non-smeary	Gradually increasing pressure applied to a 25-30 mm specimen held between extended thumb and forefinger in such a manner that some shear force is exerted on the specimen.	At failure, the specimen does not change suddenly to a fluid, the fingers do not skid, and no smearing occurs.
Weakly smeary	Same.	At failure, the specimen changes suddenly to fluid, the fingers skid, and the soil smears. Afterward, little or no free water remains on the fingers.
Moderately smeary	Same.	At failure, the specimen changes suddenly to fluid, the fingers skid, and the soil smears. Afterward, some free water can be seen on the fingers.
Strongly smeary	Same.	At failure, the specimen suddenly changes to fluid, the fingers skid, and the soil smears and is very slippery. Afterward, free water is easily seen on the fingers.

**The approximate equivalent n-values, Pons and Zonneveld (1965), are as follows:*

Deformable	< 0.7
Slightly fluid	0.7-1
Moderately fluid	1-2
Very fluid	≥ 2

TABLE 3-20

Penetration Resistance Classes.

Classes	Penetration Resistance *MPa*
Small	<0.1
Extremely low	<0.01
Very low	0.01-0.1
Intermediate	0.1-2
Low	0.1-1
Moderate	1-2
Large	>2
High	2-4
Very high	4-8
Extremely high	≥8

may be mounted on the penetrometers with flat ends as well as other penetrometers. Two 30-degree cone penetrometer tips are specified by the American Society of Agricultural Engineers (1982). One has a base area of 1.3 cm^2; the other, 3.2 cm^2. Insertion should be to where the base of the cone is flush with the soil surface. Insertion times of 2 seconds and 4 seconds, respectively, should be used for the smaller and the larger cones. A relationship between the cone tips and the specified rod with a flat end must be established before table 3-20 can be used to enter cone measurements.

Determination of penetration resistance while the soil layer is at or near its maximum water content is a useful strategy for evaluation of root limitations. The relationship between penetration resistance and root growth has been the subject of numerous studies—Blanchar et al., 1978; Campbell et al., 1974; Taylor et al., 1966; and Taylor and Ratliff, 1969. These studies suggest the following generalities which may need modification for particular plants and soils. First, if the soil material is wet or very moist and there are no closely spaced vertical structural planes, the limit of 2 MPa (6.4 mm flat-end rod) indicates strong root restriction for several important annual crops. This is the basis for the penetration resistance criterion in the criteria for physical root restriction. Secondly, between 2 and 1 MPa, root restriction may be assumed to decrease roughly linearly. Finally, below 1 MPa, root restriction may be assumed to be small.

TABLE 3-21

Excavation Difficulty Classes

Classes	Test Description
Low	Can be excavated with a spade using arm-applied pressure only. Neither application of impact energy nor application of pressure with the foot to a spade is necessary.
Moderate	Arm-applied pressure to a spade is insufficient. Excavation can be accomplished quite easily by application of impact energy with a spade or by foot pressure on a spade.
High	Excavation with a spade can be accomplished, but with difficulty. Excavation is easily possible with a full length pick using an over-the-head swing.
Very high	Excavation with a full length pick using an over-the-head swing is moderately to markedly difficult. Excavation is possible in a reasonable period of time with a backhoe mounted on a 40 to 60 kW (50-80 hp) tractor.
Extremely high	Excavation is nearly impossible with a full length pick using an over-the-head arm swing. Excavation cannot be accomplished in a reasonable time period with a backhoe mounted on a 40 to 60 kW (50-80 hp) tractor.

Excavation Difficulty

Excavation of soil is a very common activity. Table 3-21 lists classes for recording the difficulty of making an excavation. The classes may be employed to describe horizons, layers, or pedons on a one-time observation or over time. In most instances, excavation difficulty is related to and controlled by a water state.

Roots

Quantity, size, and location of roots in each layer are recorded. Using features of the roots—length, flattening, nodulation, and lesions—the rela-

tionships to special soil attributes or to structure may be recorded as notes.

Quantity of roots is described in terms of numbers of each size per unit area. The class placement for quantity of roots pertains to an area in a horizontal plane unless otherwise stated. This unit area changes with root size as follows: 1 cm^2 for very fine and fine, 1 dm^2 for medium and coarse, and 1 m^2 for very coarse (figs. 3-34 and 3-35). The quantity classes are:

Few:	< 1 per unit area
Very few:	< 0.2 per unit area
Moderately few:	0.2- 1 per unit area
Common:	1- 5 per unit area
Many:	≥5 per unit area

Roots are described in terms of a specified diameter size. The size classes are:

Very fine:	< 1 mm
Fine:	1- 2 mm
Medium:	2- 5 mm
Coarse:	5- 10 mm
Very coarse:	≥10 mm

It is desirable to have class separation at an abundance level where there are sufficient roots to exploit much of the soil water that is present in the withdrawal range of the plant over the growing season. A difficulty is that species differ in the efficiency of their roots. Soybeans and cotton are several fold more efficient than the grasses, and there are undoubtedly other differences among specific groups. The abundance classes have been formulated so that the few-common separation is about where the annual grasses have insufficient numbers of roots for seasonally complete exploitation. The moderately few-very few separation is where soybeans and cotton would have insufficient numbers.

The location of roots within a layer may be described in relation to other features of the layer. Relationships to layer boundaries, animal traces, pores, and other features are described as appropriate. The description may indicate, for example, whether roots are inside structural units or only follow parting planes between structural units.

Quantity, size, and location is a convenient order: "Many very fine and common fine roots" implies that roots are uniformly distributed, since location is not given. This contrasts to examples that provide locational information such as "common very fine and common fine roots concentrated along vertical faces of structural units" or "common very

FIGURE 3-34

Diagram illustrating the visual impressions of abundance classes of Very Fine and Fine Roots and Pores in relation to size.

FIGURE 3-35

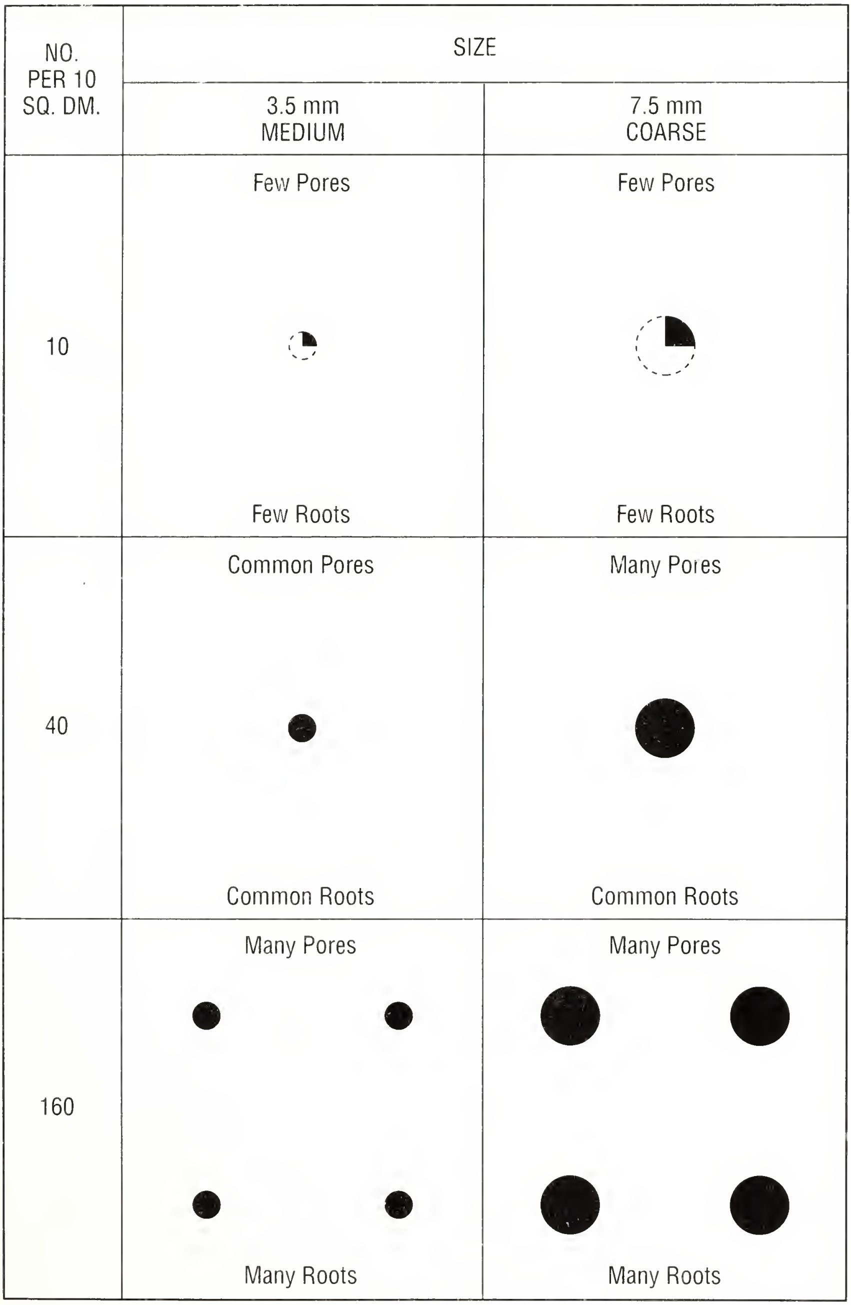


Diagram illustrating the visual impressions of abundance classes of Medium and Coarse Roots and Pores in relation to size.

fine roots inside peds, many medium roots between structural units."

In some soils, the pattern or root growth may not correspond to soil horizons or layers; therefore, a summary statement of root development by increments of 15 cm or 30 cm or some other convenient thickness is often helpful. In other soils, root distribution may be summarized by grouping layers. For example, in a soil having a strongly developed clayey illuvial horizon and a horizon sequence of Ap-A-E1-E2-Bt1-Bt2, root development might be similar throughout the A horizon, different in the E horizon, and still different in the B horizon but similar throughout the B. Root distribution in the example can then be described for the A, E, and B horizons, each horizon treated as a whole.

For annual plants, the time of the root observation may be indicated. Root traces (channels left by roots that have died) and the dead roots themselves are sometimes clues to soil properties that change with time. The rate of root decay depends on the species, root size, and the soil moisture and temperature regimes. Local experience must dictate the time after maturity or harvest that the root distribution is affected by decay. Root traces in deep layers may persist for years. Many of these traces have organic coatings or linings. They may occur below the normal rooting depth of annual crops. This suggests that they were left by deeper rooted plants, perhaps native perennials. The presence of dead roots below the current depth of rooting may indicate a change in the soil water regime. The roots may have grown normally for a few years, then killed when the soils were saturated for a long period.

In addition to recording the rooting depths at the time of observation, generalizations about the rooting depth may be useful. These generalizations should emphasize very fine and fine roots, if present, because these sizes are active in absorption of water and nutrients. The generalizations may be for a few plants or plant communities that are of particular importance. If annual plants are involved, the generalization should be for near physiological maturity.

Pores

Pore space is a general term for voids in the soil material. The term includes matrix, nonmatrix, and interstructural pore space. *Matrix pores* are formed by the agencies that control the packing of the primary soil particles. These pores are usually smaller than nonmatrix pores. Additionally, their aggregate volume and size would change markedly with water state for soil horizons or layers with high extensibility. *Nonmatrix pores* are relatively large voids that are expected to be present when the soil is *moderately moist* or wetter, as well as under drier states.

The voids are not bounded by the planes that delimit structural units. *Interstructural pores*, in turn, are delimited by structural units. Inferences as to the interstructural porosity may be obtained from the structure description. Commonly, interstructural pores are at least crudely planar.

Nonmatrix pores may be formed by roots, animals, action of compressed air, and other agents. The size of the distribution of nonmatrix pores usually bears no relationship to the particle size distribution and the related matrix pore size distribution. For water movement at low suction and conditions of satiation, the nonmatrix and interstructural porosity have particular importance.

Nonmatrix pores are described by quantity, size, shape, and vertical continuity—generally in that order. Quantity classes pertain to numbers per unit area—1 cm^2 for very fine and fine pores, 1 dm^2 for medium and coarse pores, and 1 m^2 for very coarse. The quantity classes are:

Few:	< 1 per unit area
Common:	1- 5 per unit area
Many:	≥ 5 per unit area

Pores are described relative to a specified diameter size. The five size classes are:

Very fine:	< 0.5 mm
Fine:	1- 2 mm
Medium:	2- 5 mm
Coarse:	5- 10 mm
Very coarse:	≥ 10 mm

Most nonmatrix pores are either vesicular (approximately spherical or elliptical), or tubular (approximately cylindrical and elongated). Some are irregularly shaped.

Vertical continuity involves assessment of the average vertical distance through which the minimum pore diameter exceeds 0.5 mm when the soil layer is *moderately moist* or *wetter*. Three classes are used: *Low*—less than 1 cm; *moderate*—1 to 10 cm; and *high*—10 cm or more. Additionally, the designation *continuous* is used if the nonmatrix pores extend through the thickness of the horizon or layer. Vertical continuity has extreme importance in assessing the capacity of the soil layer to transmit free water vertically.

Special aspects are noted, such as orientation in an unusual direction, concentration in one part of a layer, or such special conditions as tubular pores that are plugged with clay at both ends. Some examples of descriptions of pores are "many fine tubular pores," "few fine tubular

pores and many medium tubular pores with moderate vertical continuity," "many medium vesicular pores in a horizontal band about 1-cm wide at the bottom of the horizon."

Animals

Mixing, changing, and moving of soil material by animals is a major factor affecting properties of some soils. The features left by the work of some animals reflect mainly mixing or transport of material from one part of the soil to another or to the surface. The original material may be substantially modified physically or chemically (fig. 3-36).

The features that animals produce on the land surface may be described. Termite mounds, ant hills, heaps of excavated earth beside burrows, the openings of burrows, paths, feeding grounds, earthworm or other castings, and other traces on the surface are easily observed and described. Simple measurements and estimates—such as the number of structures per unit area, proportionate area occupied, volume of above-ground structures—give quantitative values that can be used to calculate the extent of activity and even the number of organisms.

The marks of animals below the ground surface are more difficult to observe and measure. Observations are confined mainly to places where pits are dug. The volume of soil generally studied is limiting. For the marks of many animals, the normal pedon for soil characterization is large enough to provide a valid estimate. For some animals, however, the size of the marks is too large for the usual pedon.

The features produced by animals in the soil are described in terms of amount, location, size, shape, and arrangement, and also in terms of the color, texture, composition, and other properties of the component material. No special conventions are provided. Common words should be used in conjunction with appropriate special terms for the soil properties and morphological features that are described elsewhere in this manual.

Krotovinas are irregular tubular streaks within one layer of material transported from another layer. They are caused by the filling of tunnels made by burrowing animals in one layer with material from outside the layer. In a profile, they appear as rounded or elliptical volumes of various sizes. They may have a light color in dark layers or a dark color in light layers, and their other qualities of texture and structure may be unlike those of the soil around them.

FIGURE 3-36

Cicada casts at about 0.4 actual size. The photograph is a close-up view of an indurated horizon about 35 cm thick. Cicada casts in varying stages of induration are common in some soils of semi-arid climates.

Selected Chemical Properties

This section discusses selected chemical properties that are important for describing and identifying soils

Reaction

The numerical designation of reaction is expressed as pH. With this notation, pH 7 is neutral. Values lower than 7 indicate acidity; values higher, indicate alkalinity. Most soils range in pH from slightly less than 2.0 to slightly more than 11.0, although sulfuric acid forms and pH may decrease to below 2.0 when some naturally wet soils that contain sulfides are drained.

The descriptive terms to use for ranges in pH are as follows:

Ultra acid	< 3.5
Extremely acid	3.5-4.4
Very strongly acid	4.5-5.0
Strongly acid	5.1-5.5
Moderately acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	> 9.0

Both colorimetric and electrometric methods are used for measuring pH. Colorimetric methods are simple and inexpensive. Reliable portable pH meters are available.

Carbonates of Divalent Cations

Cold 2.87N (about a 1:10 dilution of concentrated HCL) hydrochloric acid is used to test for carbonates in the field. The amount and expression of effervescence is affected by size distribution and mineralogy as well as the amount of carbonates. Consequently, effervescence cannot be used to estimate the amount of carbonate. Four classes of effervescence are used:

Very slightly effervescent:	few bubbles seen
Slightly effervescent:	bubbles readily seen
Strongly effervescent:	bubbles form low foam
Violently effervescent:	thick foam forms quickly

Calcium carbonate effervesces when treated with cold dilute hydrochloric acid. Effervescence is not always observable for sandy soils. Dolomite reacts to cold dilute acid slightly or not at all and may be overlooked. Dolomite can be detected by heating the sample, by using more concentrated acid, and by grinding the sample. The effervescence of powdered dolomite with cold dilute acid is slow and frothy and the sample must be allowed to react for a few minutes.

Salinity and Sodicity

Accurate determinations of salinity and sodicity in the field require special equipment and are not necessarily part of each pedon investigation. Reasonable estimates of salinity and sodicity can be made if field criteria are correlated to more precise laboratory measurement.

Salinity

The electrical conductivity of a saturation extract method is the standard measure of salinity. Electrical conductivity is related to the amount of salts more soluble than gypsum in the soil, but it may include a small contribution (up to 2 dS/m) from dissolved gypsum.

The standard international unit of measure is decisiemens per meter (dS/m) corrected to a temperature of 25 °C. Millimhos per centimeter (mmhos/cm) means the same as dS/m and may still be used. If it has been measured, the electrical conductivity is reported in soil descriptions. The following classes of salinity are used if the electrical conductivity has not been determined, but salinity is inferred:

Class		Electrical conductivity dS/m (mmhos/cm)
0	Non saline	0-2
1	Very slightly saline	2-4
2	Slightly saline	4-8
3	Moderately saline	8-16
4	Strongly saline	≥ 16

Sodicity

The sodium adsorption ratio (SAR) is the standard measure of the sodicity of a soil. The sodium adsorption ratio is calculated from the concentrations (in milliequivalents per liter) of sodium, calcium, and magnesium in the saturation extract:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

Formerly, the exchangeable sodium percentage, which equals exchangeable sodium (meq/100 g soil) divided by the cation exchange capacity (meq/100 g soil) times 100, was the primary measure of sodicity. The test for exchangeable sodium percentage, however, has proved unreliable in soils containing soluble sodium silicate minerals or large amounts of sodium chloride.

Sodium is toxic to some crops, and sodium affects the soil's physical properties, mainly saturated hydraulic conductivity. A sodic condition has little effect on hydraulic conductivity in highly saline soils. A soil that is both saline and sodic may, when artificially drained, drain freely at first. After some of the salt has been removed, however, further leaching of salt becomes difficult or impossible. The sodium adsorption ratio (SAR) usually decreases as a soil is leached, but the amount of change depends in part on the composition of the water used for leaching and, therefore, cannot be predicted with certainty. If the initial SAR is greater than 10 and the initial electrical conductivity is more than 20 dS/m and information is needed as to whether the soil will be sodic following leaching, the SAR is determined on another sample after first leaching with the intended irrigation water. For the land reclamation of soils with an electrical conductivity of more than 20 dS/m, the SAR is used that is determined after leaching with distilled water to an electrical conductivity of about 4 dS/m.

Sulfates

Gypsum (calcium sulfate) can be inherited from the parent material, or it can precipitate from supersaturated solutions in the soil or in the substratum. Gypsum can alleviate the effects of sodium, making possible the use of irrigation water that has a relatively high amount of sodium. Soils that contain large amounts of gypsum can settle unevenly after irrigation; frequent releveling may be required. Gypsum is soluble in water. The electrical conductivity of a distilled water solution with gypsum is about

2dS/m. In the absence of other salts, a salinity hazard does not exist except for such sensitive plants as strawberries and some ornamentals. Gypsum and other sulfates may cause damage to concrete.

Much gypsum is tabular or fibrous and tends to accumulate as clusters of crystals or as coats on peds. Some of it is cemented. Gypsum can usually be identified tentatively by its form and lack of effervescence with acid. Gypsum in the parent material may not be readily identifiable. If determined, the amount of gypsum is shown in the description; otherwise, the amount may be estimated. Semiquantitative field methods for determining amounts of gypsum are available.

A few soils contain large amounts of sodium sulfate, which looks like gypsum. At temperatures above 32.4 °C it is in the form of thenardite ($Na_2 SO_4$) and at lower temperatures in the form of mirabilite ($Na_2SO_4 \cdot 10H_20$). The increase in volume and decrease in solubility as thenardite changes to mirabilite can cause spectacular salt heaving. In sodium-affected soils, sodium sulfate is a common water-soluble salt.

Sulfides

Sulfides, mainly iron sulfide, are in some soils of tidal marshes and in some sedimentary rocks. When these materials are exposed, as when marsh soils are drained or sulfide-bearing rock is excavated, oxidation commonly produces sulfuric acid. Sulfuric acid is toxic to plants and animals in the soil and fish in nearby waters. The solutions produced are extremely acid and are highly corrosive to exposed metal and concrete. Soils and rock suspected of potential sulfur acidity are tested for the presence of sulfide salts.

A few soils with appreciable amounts of sulfides contain enough carbonates to neutralize all or part of the acidity when the sulfides are oxidized. In such soils, the total amounts of both calcium carbonate and sulfides must be known.

No reliable field methods are available for determining the amount of sulfides in marshes. The sulfide odor of marshes is not a reliable indicator of the presence of oxidizable sulfides; however, there are situations in which odor is a reliable estimate. Drained or excavated marsh soils that contain large amounts of sulfides commonly have yellow efflorescences of the mineral jarosite on the exteriors of clods.

Two field tests are commonly used to detect excess oxidizable sulfides (Soil Survey Staff, 1975). In one test, pH is measured before and after the soil is incubated at field capacity. A large drop in pH, or a pH of 3.5 or less after drying, indicates excessive amounts of sulfides. In the other test, the sample is treated with 30- to 36-percent hydrogen peroxide and heated to complete oxidation and drive off the excess peroxide.

Then, pH is measured. If the decrease in pH is large, sulfides are probably present. A meter is preferred for measuring pH because of the possibility of oxidation of indicator dyes. Special dyes suitable for this test are available.

If the field tests for oxidizable sulfides are positive, laboratory determinations of sulfur content may be required for precise interpretations.

CHAPTER 4 Mapping Techniques

Documentation

Descriptive Legend

The descriptive legend is the basic document of a soil survey and is composed of four parts: (1) description and classification of the soils, (2) identification legend, (3) conventional and special symbols legend, and (4) general soil map and legend.

Description and classification of the soils.

The descriptive legend includes descriptions of the taxa as they occur in the survey area and descriptions of map units delineated on field sheets. These descriptions form the primary reference document for identifying kinds of soils and miscellaneous areas and provide the information needed for proper classification, correlation, and interpretation. They also provide the information needed to recognize the map units in the survey area. Descriptions of the taxa and the map units, including the ranges in characteristics within the survey area, ensure that all members of the field party classify and map the soils consistently. Creating a clear, concise, accurate, and complete set of descriptions of the soils is a difficult and important job.

An up-to-date record of what has been learned about the soils is especially important when members of a survey party change. If the party leader leaves before completion of the survey area, an up-to-date descriptive legend of how the soils have been classified and mapped ensures continuity in survey operations.

The party leader organizes the information that has been gathered about the soils in an area. While preparing the descriptions, the party leader may discover matters that need clarification or supporting field data. Field studies can then be planned to clarify concepts and improve knowledge of the soils.

Guidelines for describing soils in chapter 3 emphasize individual pedons and polypedons. The soil descriptions in the descriptive legend

give the properties of pedons and polypedons plus the extent of the components in each map unit, the variations in properties and in extent of components from one delineation to another throughout the survey area, and the geographic relationships of components within each map unit and of map units to each other. The descriptions are made from detailed descriptions of pedons and polypedons, brief notes about internal properties and surface features, and summaries of transects.

As the descriptions of the soils are prepared, every map unit description is compared with the standard definition of the soil for which it is named and with the descriptions of closely related soils. The classification of the soils must be consistent with the descriptions of the soils in the map units and also with the standard definition of series or other taxa.

A table of classification is included in the descriptive legend and shows how soils in the survey area fit in the national system of soil classification as discussed in *Soil Taxonomy*. Where soil series are used in naming map units, the series can be listed alphabetically followed by the classification, or they can be arranged under the appropriate families, subgroups, and so on.

The nature, kind, position, and amount of inclusions are also described for every map unit. The extent, position, and significant differentiating characteristics of soils that are dissimilar to the major components of the map unit are particularly important. The extent and nature of inclusions that are similar to the major components should also be determined.

Written descriptive records of the soils are references for an ongoing soil survey. The properties of a soil commonly vary from one part of a survey area to another and may be evaluated differently as a result of increased experience in the area.

The soil descriptions are continually revised and updated as mapping progresses. During mapping, new map units and taxonomic units are commonly added and units that are found to be of limited extent are discontinued.

As mapping progresses, kinds of soil are often discovered that do not fit any map units in the legend. If the kind of soil is extensive and uniquely different from the soils in other map units, it is added to the legend after it has been defined by a party member and approved by supervisory soil scientists of the cooperating agencies. Some new kinds of soil can be accommodated best by redefining existing map units, and others can be accommodated as inclusions. New, approved map units must be listed in the legend promptly and defined to enable all members of the party to use them correctly.

Some soils are so limited in extent that they should be included in other map units. Two or more soils that have similar use and management

may be best combined in one map unit. Soils that are so closely intermingled that they cannot be delineated separately must be mapped as complexes. Deletions and other changes are not made formally until the supervisory soil scientists have reviewed the proposed legend changes and found them acceptable. If proposed changes are not acceptable, the agency representatives and the party leader resolve any differences they may have. A complete record is kept concerning changes in map units and the disposition of any discontinued map unit. Any changes made between field reviews are recorded in the report of the next field review.

Distinctions between map units must be larger than the ranges that normally occur in measuring diagnostic properties and locating soil boundaries. The soil descriptions must be tested to ensure that the map units are recognized and delineated consistently.

Progressive mapping by the field party is a continuing test of the legend. Inadequacies are evaluated, and any necessary changes are made in the legend. Changes are recorded on all copies of the legend, and each soil scientist in the party must clearly understand the new concepts.

Field notes are summarized periodically and the summary is recorded in the revisions of the soil descriptive legend. If observations are not summarized and recorded promptly, they may be lost or not used by other members of the survey party.

Field reviews also test the legend and its use in mapping to determine whether survey objectives and requirements are being met. Such reviews usually involve supervisory soil scientists and representatives of cooperating agencies.

The final test of a descriptive legend comes during the formal steps in soil correlation. Correlation is a continuing process from the initial descriptions before mapping starts to the final correlation. A map unit can be tentatively correlated as soon as it has been accurately described and mapped. Few changes are needed in final correlation if the descriptions are adequately tested and revised as the survey progresses.

Quality soil descriptions ensure a quality soil survey. The importance of soil descriptions cannot be overemphasized. A good set of descriptions is needed for consistent, uniform, and accurate mapping. The descriptions also provide the basic information needed for complete and accurate interpretation. Working from the soil descriptions, supervisory soil scientists can give maximum help to the survey party.

Soil surveys of lesser detail, made with more widely spaced field observations, traverses, or transects, resemble the preliminary surveys made to prepare the initial set of soil descriptions for detailed mapping. For these surveys also, map unit descriptions are modified as more is learned about the soils. Map units are added only after they have been

defined and approved by the representatives of the cooperating agencies.

Identification legend.—A symbol is placed in each delineation on the map to identify it. The identification legend is a list of these symbols and the names of the map units they represent. In some legends the names of the map units are listed alphabetically, followed by their symbols. This list of names is used by soil scientists as they map. In other legends the symbols are listed in order, followed by their names. This list is used by everyone who reads the maps. Usually both lists are prepared. If the symbols are not listed in order, as is common when new map units are added to the legend, associating a symbol on the map with the map unit it represents can be difficult.

The identification legend keys names of map units to delineations on the soil maps through the map unit symbols. Many conventions and systems are used for selecting symbols. The choice of symbols is unimportant provided the symbols are short, each symbol is unique, and the map unit that each symbol represents is named and described.

All symbols must be legible on photographic reproductions of the maps. Long symbols are difficult to place on the map without being made too small to be legible. Long symbols often must be placed outside small delineations and arrowed into them. This increases the chance of error. Experience and tests have shown that map users have great difficulty in reading field sheets that have many symbols placed outside the areas to which they apply. If the symbol is arrowed from a large delineation to a small one, many users assume that it represents the large delineation.

The map symbols serve primarily to identify map units; any connotations of soil properties are incidental. Efforts to go beyond identification and devise connotative symbols usually leads to a legend that fails to achieve its primary purpose. The connotative value of symbols may be offset by decreased legibility of the map. Map users must not assume that connotative symbols or even the map unit names describe all of the important soil properties. The set of soil descriptions (map unit and taxon descriptions) is essential to the purpose of the soil survey and should be used by mappers and by those who need the information while the survey is in progress.

Using the same or similar symbols during the mapping process and on published maps accelerates map compilation because compilers are not required to spend much time converting one set of symbols to another. Errors are reduced. Such symbols have the greatest advantage in areas where soils are well known. Where soils are not well known at the start of the survey, changes during mapping and correlation may reduce the advantages.

The following are parts of two identification legends.

Map symbol	Map unit name
AdA	Allendale loamy fine sand, 0 to 3 percent slopes
Ax	Angelica silt loam
Ba	Bach silt loam
Bn	Bonduel loam
Bo	Borosaprists
BrB	Boyer loamy sand, 1 to 6 percent slopes
BrC	Boyer loamy sand, 6 to 12 percent slopes
BrE	Boyer loamy sand, 20 to 35 percent slopes
Ca	Carbondale muck
CbA	Casco sandy loam, 0 to 2 percent slopes
CbB	Casco sandy loam, 2 to 6 percent slopes
CbC2	Casco sandy loam, 6 to 12 percent slopes, eroded
CdB	Casco-Rodman complex, 2 to 6 percent slopes
1	Almota silt loam, 7 to 25 percent slopes
2	Almota silt loam, 25 to 65 percent slopes
3	Alpowa cobbly silt loam, 30 to 65 percent slopes
4	Anders silt loam, 3 to 15 percent slopes
5	Anders-Kuhl complex, 3 to 15 percent slopes
6	Asotin silt loam, 7 to 25 percent slopes
7	Asotin silt loam, 25 to 65 percent slopes
8	Athena silt loam, 3 to 7 percent slopes
9	Athena silt loam, 7 to 25 percent slopes
10	Athena silt loam, 7 to 25 percent slopes, eroded
11	Athena silt loam, 25 to 40 percent slopes
12	Athena silt loam, 25 to 40 percent slopes, eroded
13	Athena silt loam, 40 to 55 percent slopes
14	Bakeoven-Tucannon complex, 0 to 30 percent slopes

Conventional and special symbols legend.—Conventional symbols on soil maps show many natural and cultural features other than map units and their boundaries. They help users locate delineations. Special symbols identify some areas of soils or miscellaneous areas that are too small to be delineated at the scale of mapping. All symbols must be defined. Definitions of special symbols specify the size of area that each represents.

General soil map and legend.— The general soil map helps the field party in mapping and in organizing field work. The draft of the general soil map prepared during preliminary field studies is refined as more is learned about the soils. The properties, distribution, and extent of the soils in each general area and their suitabilities, limitations, and potentials are described. Significant differences in soil moisture or soil temperature between areas can also be shown on the general soil map.

Soil Handbook

The descriptive legend is the main document that governs field operations, but it is only part of the information compiled during a survey. The descriptive legend and the other information about the soils in the survey area are organized into a *soil handbook*. The soil handbook is used by the field party and by engineers, agronomists, planners, and others who need information about the soils of the area before the survey is completed.

The handbook contains everything needed for the published soil survey, plus material that is important to the soil scientists who are making the survey. A detailed outline for the text of the published soil survey should guide development of the handbook.

Included in a soil handbook, in addition to the mapping legend are interpretations and general sections covering such topics as climate, physiography, relief, drainage, geology, and vegetation, which relate to the kinds of soil in the area. These characteristics improve the understanding of the properties, distribution, use, and management of the soils.

In addition, a record of the acreage of each map unit is maintained. In some surveys acreage is recorded progressively as the field sheets are completed. In other surveys progressive acreage records of each map unit are kept only until the unit is found to be extensive enough to keep in the legend. The final tally is made after the survey has been completed.

Some items prepared for the mapping legend or handbook may be incorporated into different sections in the publication. For example, the genetic key and classification table could become part of the section on how the soils formed and how they are classified. Some of the diagrams could be used in that section as well as in the section on the general soil map.

The descriptive legend and soil handbook should follow the same format that will be used in the published soil survey. A soil handbook that is kept up-to-date as mapping progresses will require a minimum amount of editing after the mapping has been completed.

Supporting Data

Data collected can be filed in the soil handbook. Separate sections can be added that contain all additional documentation obtained during the course of the survey. In addition, file folders, cross-indexed by soil series and map unit, can be used. Items that require simple filing systems for easy retrieval are transects, field notes, soil keys, laboratory data, special studies, special interpretations, climatic data, geology maps, vegetation maps, research reports, and any other items unique to the survey. A few of these are described below.

A *genetic key* shows the relationships of the various taxa to factors such as parent material, natural drainage, vegetation, annual precipitation, topographic position, and form, and aspects. The key should emphasize the factors associated with important soil characteristics and differences in characteristics within the survey area.

A *table of soil characteristics* highlights important properties of the soils. Comparisons can be made easily and quickly. Both the genetic key and the table of soil characteristics are particularly helpful in orienting newly assigned field personnel.

The *general soil map* helps the field party in mapping and in organizing field work. The draft of the general soil map that is prepared during preliminary field studies is refined as more is learned about the soils. The properties, distribution, and extent of the soils in each general area and their suitabilities, limitations, and potentials are described. Significant differences in soil moisture or soil temperature between areas can also be shown on the general soil map.

Remotely sensed imagery is produced from both photographic and nonphotographic sensors. The use of more than one set of imagery for reference is important. Several sets of photographs and other images are likely to yield more clues about soils than one set. The kinds of remote imagery and their advantages and disadvantages in soil mapping are discussed later in this chapter.

Photographs of soil profiles can be very effective in illustrating some soil features. Photographs or diagrams of landscapes show the relationships of soils to various landscapes. Cross-sectional and three-dimensional diagrams of parts of the survey area are also helpful.

Notes are indispensable parts of the mapping legend. Some notes are used in revising the descriptive legend, which becomes incorporated

in the manuscript for publication. Notes help make mapping faster and more accurate. They may record tonal patterns on aerial photographs that are peculiar to a certain map unit, the relationship between minor but key indicator plants, or the surface configurations that have little bearing on use or management but that help the mapper locate significant soil areas. Notes and other information needed in mapping but not intended for publication can be kept on separate sheets after each taxon or map unit description in the descriptive legend.

Maps

Imagery to Aid Field Operations

Aerial photographs are used as the mapping base in most soil survey areas in the United States today.[1] With few exceptions aerial photographs are by far the most practical mapping base for field use by soil scientists. Several kinds of aerial photography are available. Conventional panchromatic (black and white) photography is sensitive to approximately the visible portion of the electromagnetic spectrum (wavelengths of 0.38 to 0.78 micrometer). Color photography covers a similar range. Infrared photography, which covers radiation of somewhat longer wavelengths, is also available. The main kinds of aerial photography are described in the following paragraphs.

Single-lens aerial photographs.—The two basic types of aerial photographs are vertical and oblique. Single-lens vertical photographs are the best for soil mapping, although oblique or multiple-lens photographs can be used when rectified. USDA specifications for single-lens aerial photography require an overlap in line of flight of about 60 percent and a sidelap between adjacent flight lines of an average of 30 percent. With this overlap, all ground images appear on two or more photographs exposed from different air positions, providing *stereographic coverage*. Two consecutive photographs within a line of flight are called a *stereographic pair*.

If every other photograph in a continuous line of flight is removed, the remaining photographs provide *alternate coverage*. Adjoining photographs of alternate coverage in the same line of flight are *called alternate pairs*. Alternative pairs overlap about 20 percent—too little to permit stereoscopic study of the entire area. Using alternate coverage, instead of

[1] Details on procedures and techniques in the use of aerial photographs in soil surveys is provided in Agriculture Handbook 294, "Aerial-Photo Interpretations in Classifying and Mapping Soils." SCS, USDA, 1966.

full stereographic coverage for mapping, leads to problems with relief displacement during map compilation. Alternate coverage is inadequate for constructing maps by photogrammetric methods based on complete stereographic coverage.

Photographs are exposed on film at a predetermined scale and fixed negative size. The scale depends on purpose. Most USDA aerial photographs are taken with a 153 millimeter lens. Scale ranges from 1:38,000 to 1:80,000. Satisfactory enlargements up to 1:7,920 can be made from 1:40,000 negatives. Most aerial cameras currently in use expose an image of about 23 by 23 centimeters.

Photographs made directly from the original negatives at the same scale are called contact prints. In contact printing, errors cannot be rectified and the scale cannot be changed. Contact prints are economical to make and have better resolution than enlargements.

Photographs can be readily enlarged or reduced; this is one of their advantages. The process is slower and more expensive than contact printing. Some detail is lost in the preparation of enlargements, but the loss is small when skilled operators use modern processing equipment and the original negatives.

Enlarging has certain advantages. All prints for an area can be brought to a nearly uniform scale. Tilt, which causes displacement of objects and scale distortion, can be rectified. Such operations require more time than simple enlarging, but later savings may more than offset the cost of bringing photographs to a common scale. If the photograph is enlarged more than 5 times, prints are usually unsatisfactory. Enlargement increases the size of the photograph as well as the scale. The size of sheet varies with the enlargement. If the contact print at a scale of 1:20,000 is 23 cm square, an enlargement to 1:15,840 will be 29 cm square and an enlargement to 1:7,920 will be 58 cm square.

Photo indexes are inexpensive and should be obtained when available. They are useful for determining the number and location of individual photographs within an area. They are also useful for schematic mapping and for preliminary studies.

The greatest advantage of aerial photography in soil surveying is the wealth of ground detail shown. Field boundaries, isolated trees, small clumps of bushes, rock outcrops, and buildings are visible and assist in orienting the mapper and in plotting the soil boundaries and other features. Both the speed and accuracy of the work are increased by using photographs. Base maps for publication can be constructed from aerial photographs economically and in a reasonable time. Showing all of the intricate cultural and physical details, a stereographic series provides a relief model of the area.

Aerial photographs also have some disadvantages and limitations in soil surveying. Elevations are not shown. Scale is not precisely uniform. Differences of scale between adjoining photographs create some minor difficulties in matching and transferring soil boundaries. Distances and directions cannot be measured as accurately as on topographic maps or some other kinds of photographs because of distortions caused by tilt, image displacement, and other inherent errors. Finally, although far more detail is shown on aerial photographs than on most maps, the detail is not always as legible and more skill is required to interpret the photograph. Nevertheless, the advantages of aerial photographs generally greatly outweigh the limitations.

Photographic indexes are available for most of the photography available from Federal agencies. Indexes are prepared by fastening together the individual prints of an area. The images are matched, and the photographs are overlapped so that all marginal data are visible. The assembly is then photographed at a smaller scale. Most indexes prepared by the United States Department of Agriculture have a scale of 1:63,360 or 1:126,720.

Once a survey has been scheduled, photographs should be ordered as soon as possible. The order gives the exact boundaries of the survey area, the scale of photography needed, desired coverage (stereographic or alternate), and the date that fieldwork is to begin. Any special requirements, such as weight or finish of paper, are stated. Low-shrink paper is recommended for most field-mapping.

Panchromatic photography records all colors in varying shades of gray. Most modern black and white photography is of excellent quality. Because of their quality and economy, photographs made from panchromatic film are the most widely used for soil surveys.

Color photography records features of the surface in colors of the visible spectrum. The colors on the print are about the same as the colors of the features when the photograph was taken, but the colors of the ground features may be different at other times. The color of a soil also may differ, according to such factors as sun angle, atmospheric conditions, delays between flights, and moisture state of the surface. The cost for obtaining color photography is about 1½ to 2 times as much as panchromatic photography. Color prints cost 2 ½ to 4 times as much as black and white prints. Excellent black and white prints can be made directly from color negatives at the same cost as prints from a panchromatic film.

With high-altitude photography, fewer photographs are required to cover an area. Contact prints of the original negatives can be used for stereographic coverage. Enlarged stereographic coverage can be pre-

pared from selected stereographic pairs. Special stereoscopes are helpful when viewing the larger prints in field offices.

For some soil surveys, photobase maps are printed from high-altitude photography and low-shrink paper. In other surveys the photobase maps are printed on transparent film with a matte surface. Normally, field mapping on outdated photographs is transferred to film prints, and paper prints are used for new field mapping. [2]

Obtaining high-altitude photography and preparing photobase maps nearly always cost less than constructing photobase maps from a controlled aerial mosaic. High-altitude photographs have better image quality than controlled mosaic ones.

Infrared photography records a portion of the spectrum that is not visible to the human eye. Infrared film is also sensitive to part of the visible spectrum, but true infrared photography is exposed through a deep red filter so that only the infrared radiation is recorded. Prints from infrared film have distorted shades of gray in comparison to prints from panchromatic film. Bodies of water and areas in shadow appear black. Broad-leaved trees appear very light, as though covered with frost. Foliage of coniferous trees appears distinctly darker. Roads are dark, instead of very light as on panchromatic prints. These characteristics are useful for detecting patterns of soil moisture states, identifying forest types, and detecting vegetation under stress from disease or other causes. Infrared aerial photography is especially valuable in areas having atmospheric haze because the film is not sensitive to the blue portion of the spectrum that is normally associated with haze. Infrared photography costs about 10 percent more than panchromatic photography.

Modified infrared photography is a compromise between true infrared photography and panchromatic photography. The images have some of the characteristics of each. At first glance, a modified infrared photograph looks very much like a photograph made from panchromatic film. It shows more contrast between some kinds of vegetation and records differences in soil wetness in more distinctive patterns than panchromatic photographs. Modified infrared photography costs about 10 percent more than panchromatic photography. Prints from infrared negatives cost the same as prints from panchromatic film.

Color infrared photography is sensitive to the green, red, and infrared portions of the electromagnetic spectrum. It produces false colors for most

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[2] More detailed information about cartographic techniques and requirements for photobase maps are given in the "Guide for Soil Map Compilation on Photobase Map Sheets" (Cartographic Division, SCS, USDA, 1970). Photobase maps can also be prepared in a similar form from the controlled mosaics or other suitable photography.

objects. The prints are spectacular; the colors are often brilliant and contrasting. This type of photography is especially useful for the study of vegetation. Vigorously growing vegetation appears brilliant red. Color infrared photography costs about the same as conventional color photography.

Remote sensing.—refers to the full range of activities that collects information from a distance. It includes photography, which has been the most widely used remote sensing technique for many years. The range of the electromagnetic spectrum that can be sensed from a distance, however, is much greater than that covered by conventional photography. Other techniques have been devised to use part of this range.[3] Nonphotographic sensors can perceive the parts of the electromagnetic spectrum from ultraviolet (wavelengths less than 0.38 micrometers) through microwave to the upper wavelength of 100 cm.

The extent to which some of the newer remote sensing techniques can be used in soil surveys has not been fully explored. Field work cannot be eliminated, but how much it can be reduced is not clear. Soils must be examined to a depth of about 2 m or to solid rock—beyond the present reach of most remote sensors or combination of sensors. At least some clues to many soil properties are provided by surface features. It is these clues, many of them quite subtle and obscure, that are sought and used in drawing soil boundaries. These clues also assist the making of accurate soil maps without excessive digging or probing. Remote sensing contributes greatly to soil surveys by revealing these clues. The imagery extends hard data about soils and their formation to new areas.

In areas of the country where it can be used, ground penetrating radar (GPR) and statistical analysis of the radar data can be a useful aid to soil mapping and can provide an effective and efficient method to characterize variability within soil map units. GPR has the advantage of observing a linear transect of the soil continuum across a landscape.

The prospect of using more than one set of imagery is important. Such a set might be made up of two or more kinds of photography made at the same time—multiband photography—or two sets of one kind of photography made at different times of the year, or some combination of these. Although several sets of photographs and other imagery are likely to yield more clues about soils than one set, the extra cost for the additional clues would have to be justified.

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[3] Remote Sensing: "With Special Reference to Agriculture and Forestry." Committee on Remote Sensing for Agricultural Purposes, Agricultural Board, National Research Council. Washington, D.C. National Academy of Sciences, 1970.

Photograph-like images can be made by nonphotographic sensors of any part of the electromagnetic spectrum. Hence, outputs from the sensors can be viewed and treated like photographs. An example is *side-looking radar*, which can penetrate clouds and can be used at night as well as in the daytime. The radar can produce prints that resemble photographs, although the images are not as clear as panchromatic photographs. Side-looking radar is useful where continuing cloud cover prevents conventional photography. For use with computers, impulses from side-looking radar and other nonphotographic sensors can go directly into automatic data processing systems for storage or analysis.

Space exploration has added a new dimension to remote sensing. Earth-orbiting satellites can be equipped with several kinds of sensors, including cameras. Imaging from space has the same problems as imaging from aircraft and the additional problem of transmitting the data to earth. Imaging from space has two important advantages. First, large areas—thousands of square kilometers—can be examined from a single point in orbit. Second, any area can be repeatedly examined on a regular schedule.

Base Material

More than one kind of cartographic material suitable as a mapping base could be available for an area. The choice of base material depends on the relative advantages of available material for all aspects of the job, including map compilation and reproduction as well as fieldwork.

Selecting the mapping base.—The quality of the cartographic material used in mapping and for publication affects the accuracy of map unit boundaries and soil identification, the rate of progress, the methods and costs of map construction, and the quality of the published map. The assembly of cartographic materials should begin as soon as an area is selected for survey.

For most surveys, purchasing new or recent photography and preparing field sheets at the dimension and scale that will be used for publication is an economically sound practice. Some of the costly steps of map compilation are eliminated. High-altitude aerial photographs are particularly suitable, as are orthophotographs. Such photography is precise enough to eliminate the preparation of a costly controlled mosaic.

Plans for the survey must consider all costs of map construction—fieldwork, compilation, finishing, and publication. Plans must be made in advance of field operations, especially if contracts are to be let for new photography. Completion of aerial photography contracts can be delayed for a long time by adverse weather conditions.

In ordering new photography, time must be allowed for preparing specifications, awarding contracts, photographing the area, and inspect-

ing before accepting the work. The cost of original aerial photography varies greatly.

Enabling aerial photography contractors to keep their equipment and personnel busy throughout the year and taking advantage of favorable seasonal conditions reduces the cost of aerial photography. Such factors as geographic latitude and solar altitude must be considered in scheduling flights to reduce or eliminate objectionable shadows. Trees should be bare and other vegetation at a minimum for the best results. This requirement further limits the flying season in the northern half of the United States. Moisture conditions are important in revealing soil patterns. In areas of the central United States where annual row crops are the main type of crop, the lack of ground cover and soil-moisture conditions are nearly optimum for indicating soil pattern sometime between late April and the end of June. For economy, scheduling requires close study of regional weather patterns in a survey area in order to forecast the number of "photographic days" (no more than 10 percent cloud cover) in each month.

Orthophotographs.—An orthophotograph is an aerial photograph with nearly all the image displacement and scale errors removed. Aerial photographs are converted to orthophotographs by simple rectification for low-relief terrain or by differential rectification for high-relief terrain. Orthophotography is prepared by methods designed to meet National Map Accuracy Standards. Various accuracy tests are performed to verify that 90 percent of the well-defined points tested are within 12.19 meters of true horizontal position—the horizontal accuracy standards for a 1:24,000 scale. An *orthophotoquad* is an orthophotograph formatted to the same size and scale as any of the USGS topographic quadrangles.

Orthophotographs portray an abundance of detail and have correct scale and positional accuracy that is not found in conventional aerial photography. Production costs of orthophotographs compare favorably with controlled mosaic production costs. Orthophotographs of varying scales are used as base maps for soil surveys, land-use planning, resource studies, and topographic maps. Orthophotography can be enhanced with such cartographic features as contours, political boundaries, highways, and principal places to provide maps designed to meet the general need of most users.

Aerial mosaics.—Aerial mosaics are made by matching and assembling individual photographs to form a continuous image of an area. Several methods of assembly are used, and the resulting mosaics vary widely in accuracy and usefulness.

The two general types of aerial mosaics are uncontrolled and controlled. An *uncontrolled mosaic* is made by simply matching like images on

adjoining photographs without geographic control of the positions of the features. A *controlled mosaic*, displays photographs that are very close to uniform scale and rectified to reduce tilt and displacement. Features on the mosaic are close to their correct positions on the map grid. The accuracy of a controlled mosaic approaches that of a good planimetric map.

Between the uncontrolled mosaic and the controlled mosaic are a wide variety of semicontrolled mosaics for which different degrees of ground control are used. Mosaics vary greatly in accuracy and must be carefully checked before being used in soil mapping.

Because an aerial mosaic covers a larger area than a single photograph, fewer photobase sheets need be matched and the chance for error is reduced. A mosaic can be made to cover a specific area, such as a township or a drainage basin.

Topographic maps.—Topographic maps are not photographs. A topographic map represents horizontal and vertical positions of physical features by using standard symbols. Published maps usually show cultural features such as roads, railroads, and buildings in black; drainage features in blue; and contour lines in brown. Some also show additional features, such as vegetation in overprints of green or other colors.

Most topographic maps published by the U.S. Geological Survey and other Federal agencies comply with national standards of map accuracy. The standards for horizontal accuracy require that not more than 10 percent of the tested points be in error by more than a specified distance on the map. This distance is 0.85 mm for maps published at scales larger than 1:20,000 and 0.50 mm for maps published at 1:20,000 or smaller. These limits apply to positions of such well-defined points as roads, monuments, large structures, and railroads that are readily visible and can be plotted on the map within 0.25 mm of their true positions. Standards for vertical accuracy require that not more than 10 percent of the tested elevations be in error by more than one-half of the contour interval.

Because of the prescribed standards of accuracy, topographic maps published by different agencies differ little. Some variation may be noted in format, scales, sheet boundaries, and classification and selection of planimetric detail—variations due primarily to the need to meet specific requirements.

Standard topographic maps are published in quadrangles bounded by lines of latitude and longitude. Generally, topographic quadrangles cover 30 minutes, 15 minutes, 7½ minutes, or 3¾ minutes of latitude and longitude. Scale varies with topography and contour interval. The most common publication scales are 1:24,000 (the largest generally available), 1:25,000, 1:31,680, 1:48,000, 1:62,500, and 1:63,360. Coverage at 1:250,000 compiled from larger scale maps is distributed by the

Geological Survey for the entire country, and a new series of maps at scales of 1:50,000 and 1:100,000 is available for certain areas. The smaller scale maps are useful as the bases for general soil maps, for reference, and for schematic soil maps. Topographic maps can be used as the base for detailed mapping if recent large-scale maps are available for the whole survey area.

The accuracy of standard topographic maps gives them definite advantages in measuring distances and directions. The topographic pattern is helpful in understanding soil and studying drainage, irrigation, and hydrology. The detail on the maps relieves soil scientists of part of the task of recording the location of ground features while mapping.

As a base for soil mapping, topographic quadrangles lack the details—field boundaries, isolated trees and bushes, fences, and similar features—that are shown on photographs. The small scale of many topographic maps is a disadvantage. The topographic maps of recent years made from aerial photographs by photogrammetric methods are much more accurate than old topographic maps which may not be accurate and may need too many revisions to be useful.

In the United States, most standard topographic maps are published by the U.S. Geological Survey. The cartographic staffs of the Soil Conservation Service receive new lists and new quadrangles as they are published and can supply information about work in progress, expected dates of completion, and the topographic mapping program. Topographic maps needed for a soil survey can be ordered directly from the Geological Survey. Preliminary proofs or copies of manuscript material frequently can be obtained in advance of publication if the need is urgent.

Topographic maps of standard accuracy are expensive to construct and publish, but the published maps can be purchased for a small price per sheet. Besides serving as the mapping base in some areas, they are useful references.

Maps and data-base requirements.—The demand for natural resource data in SCS and the Federal sector has increased. In the past these data were displayed on various base maps that generally did not meet national map accuracy standards. Soil Conservation Service could not feasibly digitize the resource data because the use by SCS and other agencies is limited by the inaccurate bases being used. Using accurate uniform scale orthophotographs and planimetric base maps, resource data will be digitized and available for automated mapping procedures and repeated manipulation in providing various inventories and interpretative maps at great cost reduction. Repeatability of use of digitized data by SCS and other agencies, including exchanging of digitized resource data by agencies, precludes a duplication of effort in the

Federal sector and results in savings in Federal mapping programs.

Selecting Mapping Scale

The best map scale for a survey is determined by many factors. The purposes of the map are the main consideration. Soil maps in areas of intensive land uses are designed for predictions about soil use, management, and behavior in relatively small areas. The scale must be large enough to permit delineation of most areas significant for such predictions. The scale does not have to be large enough to include all property lines, cultural features, works, and structures for detailed plans to be plotted directly. A large scale increases the number of map sheets, the amount of joining of sheets, and the cost of compilation, reproduction, publication, and storage.

Most soil surveys are made at a scale of 1:24,000 or 1:12,000. A scale of 1:24,000 commonly is used for surveys in areas of less intensive land use. Scales of 1:12,000 are needed for highly detailed surveys.

Generally, the scale of mapping depends on the intricacy of the soil pattern in relation to the expected intensity of soil use. The patterns of soils are very complex in many areas where potentials do not justify a mapping scale large enough to show the patterns in detail. Where the purposes of the survey do require that small areas be delineated, the scale must be large enough to permit delineating and labeling the areas. Part of a survey area may have high value or intensive land use that justifies a scale larger than that of the rest of the area. Two publication scales can be used in such an area if the needs justify the extra costs.

Legibility of the maps is very important. Many potential users will not use maps that they can not read easily. Figure 2-4 illustrates differing legibility of the same map at different scales. Map C is clearly illegible. Map B can be read with difficulty. Map A is reasonably legible. If the map is to be published at scale B, detail that is legible only at scale A should not be delineated.

Table 2-2 gives a general idea of the smallest areas that can be shown legibly at different scales. These sizes are for isolated areas within much larger delineations. If numerous intermingled areas of the smallest size are delineated, the map will be difficult to use.

If the field sheets are made at the planned publication scale, the amount of detail that should be drawn in the field is limited to that judged adequate for the purposes of the published survey. Using the publication scale also eliminates the necessity of transferring the field mapping to a different scale. If mapping scale is larger than publication scale, the surveyor should try to visualize what the map will look like at publication scale. A reducing lens can be used.

Reference Maps

Many types of maps are published by public and private agencies. They range from small-scale road maps prepared by oil companies and county highway maps prepared by State highway departments to the large-scale detailed maps used in city planning.

Most reference maps are designed, constructed, and reproduced to meet a special purpose. Necessary details are emphasized and others are subordinated. On small-scale road maps, for example, highways, highway numbers, towns and cities, points of interest, and mileages are prominently shown; drainage, railroads, pipelines, powerlines, and public land lines are omitted or subordinated.

Aeronautical charts.—These are designed and constructed specifically for air navigation. The scale is small so that large areas can be shown on a single sheet. Ground features that are prominent from the air are emphasized in bold and simple symbols. Other features of equal importance on the ground but less noticeable from the air are subdued or omitted entirely. Elevation is shown by gradient tints. Navigational data are shown by bright overprinting.

Plats.—These are prepared from public land surveys and are designed to present land survey data. They usually cover a survey unit, such as a township. The scale is large. Courses and distances, subdivisions of sections, acreage figures, and other data from the survey are shown. Cultural and drainage features are reduced to a minimum and are accurate only on the survey lines.

Special-purpose maps have little value as bases for detailed soil surveys. Such maps are very useful for references, however, and they may be the best base maps available for surveys of remote areas. Aeronautical charts, for example, are useful for rapid small-scale surveys of large areas.

Many other kinds of special maps are available for some areas. These include maps of published soil surveys, maps of geology, maps of forest or other vegetative cover, coast and harbor charts, census maps, U.S. Postal Service maps, and highway maps. County highway planning maps are available for many areas and are good references. Some State highway or transportation departments make good small- to medium-scale highway planning maps for internal use that can be reproduced with special permission. Maps protected by copyright cannot be reproduced without permission.

Index Maps for Field Sheets

An index map is prepared to show approximately the location of each

field sheet. A useful scale is about 1:125,000. Many States have county highway maps at about this scale, and many of these are good bases for preparing the index.

The mapping limits of each field sheet are drawn on the index map, and the field sheet number is written in each area. The preferred position for the label—"Index to Field Sheets"—is at the top center. Indexing by column and row makes the sheets easy to use. For example, if the northwest sheet is 1-1 (column 1, row 1), then the next sheet south is 1-2 (column 1, row 2), and the sheet east is 2-1 (column 2, row 1). The index accompanies the completed survey when it is submitted for map assembly.

Field and Office Activities

Preliminary Research

The soil survey party leader should arrive in the area before soil mapping begins and generally before the other party members do. This allows the party leader time to become familiar with the area, review preliminary data, investigate the major soils and their pattern of occurrence, review the stated purposes of the survey, check the adequacy of the base map material, and prepare a preliminary mapping legend. During the general premapping appraisal of the survey area, the party leader also assembles the information needed to schedule survey operations.

A well-established principle of research is to assemble the existing information about a subject first. Time and effort are saved and costly errors are avoided if what is already known is used. The time required to find and appraise existing information is usually small relative to the time required to compensate for failure to use the information. Even for areas about which little is thought to be known, a diligent search usually uncovers useful information. In addition, information about adjacent areas can often be applied to the survey area.

If an older soil survey has been made, it is generally the most important reference available. Soil surveys made in the United States before 1920 emphasized the character of the parent material. The maps commonly provide some of the best information available for dividing the survey area into sections within which parent material is reasonably uniform. Many soil surveys made between 1920 and 1930 provide most of the information needed to broadly characterize the area and its soils. Those made between 1930 and 1940 provide a very important part of the information needed for identifying map units. The earlier surveys are also useful for identifying map units, but they must be used in conjunc-

tion with a systematic preliminary field study. It is helpful to examine mapping and examples of established soil series in nearby areas that have been recently surveyed.

Unpublished soil surveys of scattered farms are another source of information about the area. The value of this information depends on the quality of the legend and consistency of mapping over long periods. Regardless of the quality of the legend, the scattered farm mapping should not be made a part of the modern soil survey without careful field checking.

A soil survey is a study of the geography of soil. Maps detail geographic information. Aerial photographs, topographic maps, and other maps are useful references whether or not they are used as the mapping base. Each kind of map shows features that the others do not.

Topographic maps are the best references for appraising relief for most areas. Maps and texts on geology for many areas have been published by the U.S. Geological Survey and by comparable State agencies. The publications are on various subjects, such as bedrock geology, surficial deposits, and water or mineral resources. The maps were made at various scales and degrees of detail. Almost all contain important information about the parent material of soils and related factors. Although not as extensive as for geology, maps showing vegetation have been published for many areas. The U.S. Forest Service and State agencies are likely sources. In addition, climatic maps that are commonly at small scale and general in nature are available. The cartographic staff of the Soil Conservation Service, local libraries, and university libraries are good sources of information about what has been published and where it can be obtained.

Local sources—libraries of local schools, universities, municipals, historical societies, State agencies—are sources of published material on soils, agriculture, geology, geomorphology, hydrology, climate, engineering, biology, history, and related subjects. If a university is located within reasonable distance of a survey area, graduate theses may provide significant material. Local weather stations can provide data on temperature, precipitation, and other weather events. Reports of the Bureau of the Census and of USDA's Economic Research Service and National Agricultural Statistics Service are authoritative references on land use and crop production. A computerized bibliographic search service can also provide references for publications about the survey area.

Faculty members of universities often have information that is not available in published form or know of published information that the party leader has not found. The local representatives of the Cooperative Extension System, area and district conservationists of SCS, and voca-

tional agriculture teachers may also be sources of knowledge that is not generally available. Representatives of planning boards, sanitation departments, highway departments, and the like are knowledgeable about matters that are important for interpreting soils and designing map units. Strong working relationships with the office of the State geologist and with geologists working in the survey area are very important. They can provide much information that is helpful in understanding soil-rock relationships.

Some information not directly related to soils is also helpful in planning, organizing, and conducting a soil survey. Questions that should be answered include:

1. What is the present land-use pattern? Is it relatively uniform or a mixture of conflicting uses and intensities? Are there political or economic problems associated with present land uses?

2. Is there a land-use policy or plan for the area? Is it active and effective? What changes in land use does it outline?

3. What is the general ownership pattern? Is it expected to change?

4. Are mineral rights important in the area? Who owns them?

5. Are water rights, either ground or surface, controlled? Does water supply limit land use and continued growth and development? What is the quality of the water?

6. What cultural, social, or economic factors influence or control land use?

7. What qualities of the area (climate, soils, mineral, and so forth) are unique, valuable, or limiting for some uses?

Not all of these questions are universally important, nor is the list complete. The answer to these questions, however, can be important in satisfying the needs for the soil survey.

Promising sources of reference material have been mentioned. The amount and significance of existing information varies widely, but in most parts of the United States it is substantial. Preliminary research can provide much, if not most, of the information about the soils of the area and their geography that is needed to start field studies and prepare a preliminary mapping legend. Preliminary research provides the basic data for interpreting the soils.

Preparing the Mapping Legend

Preparing the mapping legend is the principal duty of the party leader after preliminary field studies have been completed. The purposes of the survey having been stated in the memorandum of understanding, the party leader consults with other specialists and determines what soil areas are significant. Soils and map units that can be consistently identified and mapped are then described, and names and symbols are proposed for them.

The mapping legend is composed of two parts: (1) the descriptive legend, which contains descriptions and classification of the soils, the identification legend, the legend of conventional and special symbols, and the general soil map and (2) mapping aids such as a genetic key, table of soil characteristics, and notes about individual soils or map units. The mapping legend contains the primary references and the principal guides for each survey party member. It is designed to serve the purposes of the soil survey and is unique to each area.

Preliminary studies are made in a survey area to identify sets of soil properties that are repeated in characteristic landscapes and are mappable. Not all of the soil map units needed for the complete survey can be anticipated at the start. An initial mapping legend is prepared after preliminary investigations and test mapping. The initial mapping legend should include only the descriptive legend and mapping aids for those soils, map units, and other features that have been definitely identified as needed. The number of map units in the initial legend depends on the scope of the initial studies, complexity of the area, and intensity of the survey. Map units must be defined and described carefully. These descriptions are the guidelines for mapping soils and the standards against which possible additional map units are evaluated as the survey progresses. The mapping legend should be made available to each member of the party before mapping begins. It is revised as needed during the soil survey.

As the survey progresses, other material is added to the mapping legend. This makes a soil handbook for the survey area. The soil handbook contains all of the information and other related facts about the genesis, morphology, classification, and interpretation of the soils of the survey area. By the time mapping is completed, the soil handbook should contain all of the material needed for the published soil survey.

Field Operations

Soil mapping is a technical art. It requires sound training in soil science and familiarity with the principles of the earth sciences. A skilled soil

scientist is a perceptive observer and understands the significance of landscape. Subtle differences in slope gradient or configuration, in landform, and in vegetation can be important indicators of soil boundaries. The soil scientist must learn to associate sets of landscape features with sets of internal soil properties to be able to visualize the pattern of the soils. A skilled mapper is able to abstract the essentials of the soil pattern and sketch this pattern on a map.

Above all, a good soil scientist strives for accuracy and is truthful about the reliability of the maps. The demanding standards for soil mapping must be maintained throughout such a survey regardless of vegetative cover.

Even though the map scale is adequate and the legend is well designed, the legibility and usefulness of the maps depends on the skill and judgement used in applying the legend. Some soil boundaries are more important than others and require greater accuracy. Time and effort must be spent to delineate small areas of soil that contrast with neighboring soils. In mapping consociations, for example, boundaries between highly contrasting soils, such as a wet soil and a dry soil or a clayey soil and a sandy soil, must be located as correctly as possible.

The greatest time and effort is spent delineating dissimilar soils that are more limiting for use than nearby soils. Small areas of some soils are deliberately mapped with their more extensive neighbors if the two kinds perform similarly for the purpose of the survey. Useless detail is avoided. Special symbols are used to indicate significant areas too small to be delineated. The skill and judgment of the mapper are part of the art of separating the landscape into meaningful units of soil and then recording the units on a map.

Using Aerial Photographs.—Aerial photographs provide important clues about kinds of soil from the shape and color of the surface and the vegetation. The relationships between patterns of soil and patterns of images on photographs can be learned for an area. These relationships can be used to predict the location of soil boundaries and kinds of soil within them.

Light and dark tone on panchromatic photographs and color differences on color photographs, for example, are records of light reflected when the photographs were taken. These records must be interpreted by relating the visual pattern on the photographs to soil characteristics found by inspection on the ground. Using the aerial photographs of an area, a soil scientist learns many relationships between the photographic images and soil and landscape features, but many uncertainties inevitably remain. Awareness of the factors that affect an image is required to interpret the aerial photographs as fully as possible.

The techniques used to predict specific kinds of surface features, landforms, attributes of soils, and soil boundaries from photographs are continually being refined. Published material provides information about the techniques and the kinds of clues used by photo interpreters. Some publications provide helpful illustrations of specific features. Nevertheless, reliable predictions of many features in a particular area require experience in relating the images on the photographs to what is actually on the ground.

Such features, as roads, railroads, buildings, lakes, rivers, field boundaries, and many kinds of vegetation can be recognized on aerial photographs.

Relief can be perceived by stereoscopic study. Shadows and differences in tone between slopes that faced the sun and those that did not at the time of photography also help show relief. Relief features help locate many soil boundaries on the map. Relief also identifies many kinds of landforms which are commonly related to kinds of soil.

Many landforms—terraces, flood plains, sand dunes, kames, eskers—can be identified and delineated reliably from their shapes, relative heights, and slopes. Their relationship to streams and other landforms provide additional clues. The soil scientist must understand geomorphology to take full advantage of photographic imagery.

Some landforms are less easily identified, but most images contain clues that narrow the choices of the kinds of landforms represented. Experience in interpreting tone patterns, configuration of relief, and patterns of drainageways commonly permits correlation of these patterns with kinds of geologic deposits and geomorphic features in an area. As the survey progresses, experience generally increases the reliability of predictions.

Differences in tone or color may reflect soil differences. Differences caused by man-imposed land use usually can be recognized by the angular shapes and abrupt boundaries of the areas. Other tonal differences may reflect differences in vegetation that relate to soil or differences in the surface of bare soil. Certain patterns of tone or color may reflect local soil patterns within areas that can be mapped in one day. Different soil associations have distinctive patterns that can be recognized on photographs. These patterns serve as bases for drawing tentative soil boundaries and for predicting kinds of soils. These predictions of soils and boundaries must be verified in the field.

Accurate soil maps cannot be produced solely by interpretation of aerial photographs. Time and place influence the clues on the photographs. Shades of gray commonly reflect the state of the soil moisture when the photograph was taken; but the soil moisture changes with time. Clues to soil boundaries that are evident on photographs taken at one time are not necessarily evident at another time. The activities of

man have changed patterns of vegetation and confounded their relationships to soil patterns. The clues must be correlated with soil attributes for each set of photographs, and predictions of soil properties from such clues must be verified in the field. The accuracy of maps improve as fieldwork and experience increase.

Stereoscopic examination.—Before an area is surveyed, making a careful stereoscopic study is helpful (fig. 4-1). The area is scanned with a stereoscope for a general impression of farming, relief, geology, landforms, kinds of soils to be expected, soil moisture states, and so forth. Important features that can be accurately identified are sketched lightly on the photograph. Some features can be determined with more certainty than others. Images that help identify obscure features can be marked. The following steps are commonly used in preliminary studies.

1. Drainageways, streams, and ponds are tentatively sketched.

2. Roads, buildings, and other location references are identified.

3. If soils have been mapped along the match line with an adjacent photograph, the soil boundaries are transferred to the outside edge of the match line. Some soil boundaries can be tentatively extended onto the unmapped sheet.

4. Additional features can be lightly penciled if they can be identified with confidence: boundaries of flood plains and stream terraces, boundaries of wet areas and water, prominent landforms such as escarpments and areas of rock outcrop, gravel and borrow pits, ridge lines, sinkholes and wet spots.

Routes of traverse can be placed during these preliminary studies. Obstacles can be identified and plans made to avoid them. Enough field checking is planned to ensure maximum accuracy with a minimum of walking per unit of area mapped.

As experience is gained in an area, many soil boundaries and kinds of soil can be tentatively predicted on the photographs. These predictions must be verified in the field, but preliminary interpretation can increase the quality of mapping. During such preliminary studies, a map should not be cluttered with conjectures. Only features that can be predicted with confidence are marked.

After fieldwork, mapped sheets are examined again while the landscapes are fresh in the mind and can be related to the stereoscopic images. If considerable time elapses, details may be forgotten. Questions

FIGURE 4-1

Stereoscopic study of an area prior to field work is helpful.

that the examination may raise become more difficult to resolve, and a special trip to the field may be needed. Because dense vegetation or other conditions may obscure the image on a photograph, some drainageways, slope breaks, and soil boundaries that are observed in the field may be impossible to place accurately on a photograph. These features can be sketched tentatively in the field, and their locations later checked by stereoscopic study for necessary revision. Thorough stereoscopic study of areas that have been mapped commonly reveals places where soil boundaries or stream symbols need to be refined to conform to relief. The traces of roads in heavily forested areas may be obscure on single photographs but evident under the stereoscope. If some boundaries inadvertently were not closed during field mapping, they can often be closed with confidence on the basis of stereoscopic study.

In the field, roads, houses, streams, field boundaries, individual trees or bushes, and the like are used to identify locations on the ground with points on the base map. The photograph can be oriented so that the relative position of its images corresponds to the relative position of ground features from the vantage point of the surveyor. The photographic images of surface features that mark soil boundaries can be followed in the sketches of the boundaries. Boundaries that are not evident on the photo-

graph can be sketched in relation to identifiable ground features.

In some areas a stereoscope used in the field with stereoscopic pairs of photographs is helpful. A pocket stereoscope can be used on the hood of a vehicle or on a dropleaf shelf (fig. 4-2). It can be carried while walking. The stereoscope and pairs of photographs can be used to relate the landscape features to the stereoscopic images. Kinds of soils and the location of boundaries can be predicted from the stereoscopic image. Boring or digging is needed to identify soils positively and to verify predictions, but stereoscopic study commonly reduces the number of borings that are needed to locate the boundaries of an area.

Plotting soil boundaries.—A soil scientist plans the day's work as a series of trips across the area to be mapped. Proceeding along these routes, the soil scientist predicts soil areas, the kinds of soil in the areas, and the boundaries that separate different kinds of soil. These predictions are checked as the areas are crossed. Finally, boundaries and kinds of soils are plotted on the map. Thus, fieldwork consists of a sequence of predictions and verifications.

To the extent feasible, mapping is scheduled to proceed systematically across contiguous areas. When mapping is resumed each day, the mapping of the previous day provides points of reference. The boundaries that were projected tentatively the day before are predictions to be verified. The soil patterns and the clues for interpreting the landscape are already understood. Mapping systematically across contiguous areas

FIGURE 4-2

Using a common pocket stereoscope.

contributes greatly to both efficiency and quality of the work.

Ground traverses are planned to cross as many soil areas as possible. Soil areas generally conform to the orientation of relief, which is commonly related to drainage courses. Consequently, most soil areas and most soil boundaries can be crossed by traveling at an angle to the secondary or tertiary drainage courses. The traverses are spaced so that the boundaries that are identified and projected on one traverse can be identified and continued on the next. Traverse spacing depends on the complexity of the soil pattern, visibility, and amount of detail required by the survey objectives. In fairly detailed surveys, for example, traverses are planned to pass within 200 to 400 meters of every point in the area, thereby permitting detection of small areas of contrasting soils.

Where aerial photographs are used as the mapping base, a predetermined line of traverse need not be followed consistently if there are sufficient reference points for accurate location. A traverse can deviate from a planned route to cross landscape features that may be marks of soil boundaries. Wandering from place to place at random, however, should be avoided. Aerial photographs assist in avoiding obstacles on the route. If boundaries are observed to run in a different direction than had been anticipated, the plan can be adjusted.

From any point of observation, the soil scientist looks along the projected route and predicts the kinds of soils on the landscape ahead. A break in slope gradient, a change from convex to concave slope configuration, a change in the color of the surface of a plowed field, the margin of a swamp or forest, the edge of a stony area, a change in kind or vigor of crops—these observable features can be related to soil boundaries. If possible, these features are identified on the aerial photograph. Some may already have been marked during the stereoscopic examination. If soil boundaries follow identifiable features, they are lightly traced on the photograph in pencil. Boundaries that are not evident on the photograph are sketched on the map in relation to identifiable features. Most features must be located and sketched by estimating location in relation to the point of observation and other known points. Tentative soil boundaries are sketched for perhaps 100 to 200 meters ahead and on either side of the point of observation. Natural and cultural features that are immediately ahead, such as a stream or drainageway, are also sketched on the aerial photograph.

Some soil boundaries are sharply defined (fig. 4-3). Others are plotted as lines midway in zones of gradual transition from one soil to another (fig. 4-4). A judgment is made about whether a broad transition zone is a discrete mappable soil unit or should be split and its parts included with the soils on either side. Every part of the mapped area

FIGURE 4-3

Sharply defined boundary between sandy soils on a high terrace (at right) and loamy soils on a lower terrace.

must be enclosed in a boundary and assigned a symbol.

After predictions are made about the soil areas and boundaries are sketched on the map, the soil scientist walks across the predicted boundaries. The course is adjusted as necessary to investigate the transitional zone and any unusual features. Slope gradient is estimated or measured with an Abney level or a clinometer. As a predicted soil boundary is approached, especially in a broad transitional zone, the soil is examined to locate the significant changes in soil properties.

As a projected delineation is crossed, the distribution of microdepressions, microknolls, tiny areas of different vegetation, convexities and concavities, and other features too small to delineate are observed. The soil is examined at a place where the microfeatures suggest that the predicted dominant soil should be best expressed; and this portion of the delineation is identified positively. The prediction may be confirmed, or a different kind of soil may be found. Where microfeatures suggest important inclusions, additional observations are made to ensure that the evaluation of the whole delineation is good. Sites for examination are not chosen at random if reasons exist for dividing the projected delineation into parts that are the predicted soils and parts that are not.

The number of places at which observations are made depends on the certainty of the predictions and the objectives of the survey. If predictions about the kind of landscape under examination have been valid

FIGURE 4-4

Broad transition zones between contrasting soils. Dark areas are Brookston soils; light areas are Crosby soils.

many times before, soils need be examined in only a few places. If the landscape features have not been consistently related to kinds of soils, many places must be examined. The depth of the examinations depends on the depth of differentiating criteria for the map unit and on the confidence in the predictions about the kind and uniformity of soil material at a given depth. The examination itself is rapid and is mostly a search for a few properties that identify the soil. A small sample of a pedon is observed; seldom is an entire pedon studied.

After a delineation has been identified and crossed, the soil scientist turns and looks back on the landscape from a new vantage point. A final judgement is made on the boundaries and symbols. If mapping is done on an aerial photograph, the photographic images are checked against the landscape features before the final boundaries are sketched.

Soil boundaries are projected on either side of the traverse as far as they can be seen and identified with reasonable certainty. The ends of their projections are checked from the next traverse. Many boundaries can be seen throughout their lengths. Other boundaries can be predicted on the aerial photographs with a high degree of certainty. In forests, for example, visibility may be a few tens of meters or less; but, where a slope break that marks a soil boundary can be seen under the stereo-

scope, the boundary can be plotted much more accurately by a study of the photographs than by an observation on the ground. A soil boundary that is found at one point to correspond to a change in color on the photograph is commonly continued along the change on the photograph even though the boundary itself is not visible on the ground during mapping. In detailed soil mapping many boundaries between traverses are drawn on the basis of variations in the photographic image.

In mapping, a pattern of soils and landscapes is conceived, rather than a group of individual map units. Certain soils are typically found together. The number of soils in any locality is usually small.

In most places landscape features mark the kinds of soils. But landscape features do not identify soils everywhere, and by no means can all internal soil properties that are used to define map units be correlated with external features. Where soil boundaries cannot be predicted with confidence, they may be identified by direct examination of the soil.

In some areas, important attributes of the subsoil or substratum are not related to surface features. Depth to bedrock, layers of contrasting texture, salt in the substratum, and similar attributes may have no visible relationship to the vegetation or other natural features but may be important when the soil is used. When desert is irrigated, when wet soils are drained, or when highways are built, soil differences that are not reflected in landscape variations may become important.

Conditions of this kind occur in most survey areas. If common mapping techniques are used, the predictions frequently turn out to be inaccurate for some areas. Unless the mapper can reappraise the landscape and reliably predict the extent of the soil, the boundaries must be determined by actual examination.

In large areas where landscape has low predictive value, geologic history and geomorphology may provide guides to stratigraphy, depth, and distribution of the kinds of rocks that are related to specific soils. The general hydrology of an area may indicate where salt-charged water has moved and where the salt has concentrated. Streams and their traces help in locating areas that have layers that differ in texture. As much preliminary information as possible is assembled to help determine the pattern and scale of soil variability. This information helps in planning the route and spacing of traverses and the spacing of samples within the traverses.

In survey areas that are to be irrigated, samples of critical layers may be taken for special field-testing or examination to determine boundaries. These samples may be taken at points on a predetermined grid or at predetermined points along lines of a traverse.

Where internal properties of soils are used for locating bound-

aries, a predetermined line of traverse is generally followed. Side trips are made wherever landscape features or experience with the soil pattern indicates that there is probably a significant soil change between traverses. Generally, the soil is examined at some standard interval along the traverse to locate important differences. If properties deep in the soil are important, the plan may require observations at fixed depth-intervals to a certain depth, such as 1 meter, and with layer depth intervals to greater depth.

In most areas, some feature of the landscape or some aspect of the pattern of soils already mapped on an adjacent traverse provides a basis for predicting the location of soil boundaries. As evidence of change is observed, preliminary observations are made. Where the evidence indicates an important soil boundary, the soil is examined in more detail or to a greater depth to verify the prediction.

Where power equipment can be moved freely across the countryside, it can be used to examine the soil to considerable depth at close spacing. Map units that are based on soil properties deep below the surface can be delineated with increased accuracy and the rate of progress can be greater if the geographic distribution of these properties is consistent with the scale of mapping.

Neither standard intervals between traverses nor intervals for investigating the soil within traverses can be specified with certainty. The plan is adjusted to the direction and scale of the soil boundaries and the variability of the important properties. This kind of evidence is commonly obtained as the survey progresses, and the mapping plan can be altered to fit the accumulated evidence.

A great deal of skill and judgement is required in areas of low predictability. Rarely are the soils at two sample sites exactly alike. Study of a single site is not enough to identify a significant area. Map units are defined to include the variability within areas large enough to be meaningful for the objectives of the survey. Using preconceived ideas of significant limits of definitive properties to define map units without regard to their geographic distribution generally results in unmappable units. Meaningless boundaries may result. Delineations should show the pattern and scale of orderly variation of soils. The kinds of variability over short distances should be noted in the descriptions of the map units.

In all soil surveys distinctive landscapes are outlined on the map first. In surveys where most map units are fairly large and contain more than one kind of soil, landscape patterns are identified mainly by interpretation of aerial photographs, by aerial observation, and by study of topographic maps, geologic maps, land-use maps, and other

available information. The size of the outlined areas depends on the objectives of the survey and the landscape pattern. Preliminary areas are of course no smaller than the smallest delineation that will appear on the soil map. They are often much larger. In 3rd-, 4th-, and 5th-order surveys, however, most map units are made up of more than one kind of soil or miscellaneous area and usually coincide with the landscapes outlined in preliminary work.

Traverses of the preliminary delineations may be desirable, depending on the level of generalization required for the survey and the complexity of the soil patterns. The plan of traverses usually is based on interpretations of photographs, but this plan should be tested in the field.

In areas of low accessibility, roads or trails may be traveled; but the mapper must understand that roads and trails commonly follow the easiest routes and avoid the steepest slopes, the wettest areas, and the other places that are difficult to cross. Such places are integral parts of soil associations and should be observed by the mapper on the ground.

Transects are commonly used to determine the composition of map units. In transecting, a planned line of travel is followed as closely as possible and the soils are observed at predetermined regular intervals.

In transecting, routes of travel are systematically planned to give a valid sample of the area. Taxa phases and other features are identified and recorded. Distances or number of points along the route identified by each taxon provides estimates of the composition of the map units. In surveys without easily predictable patterns, soils are sampled most efficiently if the transect lines are selected at random. Lines oriented to cross the drainage pattern often provide the most information about the pattern of soils.

Sample blocks, instead of transects, are used in some surveys to determine the composition of map units. Blocks do not replace transects, however, they permit one to observe spatial patterns not always evident from transects. Sampling by transects is usually more efficient than block sampling for estimating map unit composition.

Methods for sampling by blocks vary among soil surveys. One method imposes a grid of appropriate divisions on the entire area. Grid segments are numbered, and sample blocks are selected by drawing numbers at random. Each sample block is remapped in greater detail, and the area of each kind of soil is measured. These data provide estimates of the kinds and proportions of soils in each map unit. The number of blocks and their sizes are determined by statistical principles with consideration of mapping scale, the limits of confidence required for the survey, the general pattern of soils, and the relative size of soil areas.

Mapping of organic soils follows the same general principles as

mapping of mineral soils. Organic soils, however, have some special relationships to landscape and vegetation. These relationships affect mapping of organic soils at all levels.

In preparing the mapping legend, systematic investigation of organic soils is required as for other kinds of soils. A thorough knowledge of the genesis of organic soils is required, as well as high-quality imagery and appropriate tools.

The kind of organic soil in many areas is closely related to the kind and pattern of native vegetation. Since many areas of organic soils are comparatively undisturbed, reliable relationships between soils and plant communities can be established. Thus, high-quality imagery from aerial photography and other forms of remote sensing can be very useful in preparing legends and in mapping these soils.

Where organic soils have formed directly on a mineral substratum, the environment may be rather uniform over extensive areas. Although the kind of organic material can vary with depth because of changes in climate over the period in which the soils have formed and because of differences in rate of decomposition that result from the accumulation of the organic material, such variations commonly are uniform over large areas. The properties of a large area of organic soils, therefore, can be accurately estimated from the properties of a small sample.

Organic soils are not uniform in some areas that have microrelief of hummocks and swales. The hummocks commonly contain fibric material, and the swales contain hemic and sapric material. In such landscapes, many more sites must be examined to determine the nature of the soils.

These relationships and processes generally apply where organic soils are formed by lake filling. Each basin in which organic soils have formed has a unique local environment, and the organic soils in adjacent basins may differ considerably. This is particularly true in irregular glacial moraines. For example, limnic materials may be covered by only a thin mantle of organic material in some basins and by several meters of organic material in others.

Areal relationship must be kept in mind when estimating the extent of the different soil components within basins, particularly small basins. For example, one kind of organic soil occupying a rather narrow fringe of a bog may cover a greater area than the organic soil in the center.

In northern glaciated areas in particular, organic soils may form around the edges of swamps that have open water in the center while adjacent swamps lack surface water.

In some areas, a layer of water can underlie the organic soils at a relatively shallow depth. Such areas may not support much weight and

should be investigated with caution.

Organic soils of some coastal wetlands lack distinctive landscape features and, additionally, are poorly accessible. In these areas, the soil scientist relies on other features to predict kinds of soils. Patterns and kinds of soils in many coastal areas can be related to the position of such natural features as shores, deltas, streams, and adjoining higher lands. The soil scientist must have a thorough knowledge of the geomorphic history of the area in order to make reasonable predictions related to such features and to determine the places where transects and other field checks will best verify the predictions.

Completing Field Sheets

Most soil survey field sheets are individual photographs or compiled photobase maps. As each field sheet is completed it is joined with adjacent sheets and checked for errors.

Joining field sheets.—Each pair of adjacent field sheets shares a common match line. During mapping, soil boundaries are commonly extended beyond the match line to be transferred to the adjacent sheet; but when the field sheet is completed, soil boundaries and other features may be discontinued at the match line. The mapping on each field sheet should be carefully matched with that on adjacent sheets to check boundaries and delineations. Roads and streams also should be continuous from one sheet to another. Special care is needed at the corners where four field sheets join.

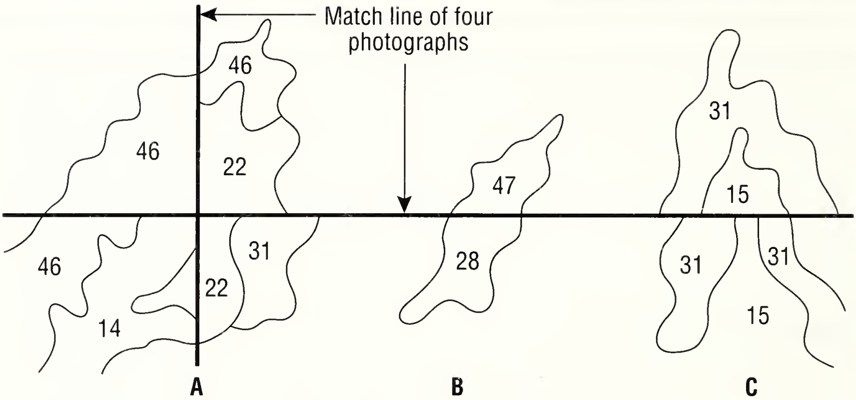
If soil boundaries are sketched on overlays, field sheets are matched before soil lines are transferred to the soils overlay. Matching should be completed while the photographic background is available.

The mapping on one field sheet can be matched with that on an adjacent sheet in several ways. For aerial photographs, the mapped field sheet and an adjoining unmapped field sheet can be placed under the stereoscope and the images meshed. The soil boundaries and other features on both sides of the match line can then be transferred from the completed field sheet to the unmapped sheet.

Another method, that is particularly useful if adjoining sheets vary in scale, is to transfer boundaries by reference to the photographic images. The relationship of the soil boundaries to images of isolated trees, clumps of bushes, field corners, and the like are observed along the match-line. Images of the same features are located along the match line of the adjoining photograph, and the boundaries are transferred or checked in relation to the images.

When the second field sheet is mapped, boundaries of delineations that cross the match-line may be altered. Consequently, the boundaries

FIGURE 4-5



Failure to join adjacent field sheets: *A*, boundaries do not match where four field sheets join; *B*, boundaries match but symbols do not; *C*, symbols match but boundaries do not.

at the match-line must be rechecked after both field sheets have been completed. If different individuals map adjacent field sheets independently and the completed sheets are joined, a match indicates the uniformity of fieldwork.

If there is no systematic method of joining sheets, errors are easily made that may require additional fieldwork before the final map can be compiled. Figure 4-5 illustrates some errors on unmatched field sheets.

Inking field sheets.—After mapping has been completed on each field sheet, it may be inked to provide a permanent record and to provide a map from which copies can be made (fig. 4-6). All soil boundaries and symbols and important drainage features should be inked. Cultural features needed on the soil maps are determined before mapping starts and are specified in the legend.

Inks or leads that are reproducible photographically and are readable by automatic scanning equipment are preferred. The ink or lead used should be compatible with the base material, and the lines should be opaque. Several kinds of inks and leads are suitable. Commonly, pens that store carbon-base ink in a reservoir are used.

Several pens that make uniform lines of different thickness are needed for inking different features and for lettering. Line widths recommended for different features are indicated in the list of conventional symbols on fig. 4-7.

Different groups of features generally are inked in separate operations. Drainage is inked first and inspected to see that individual streams are properly joined, matched, and classified. Then, culture is inked. The

classification of roads and other features is checked at the same time. Soil boundaries and symbols are inked next. Finally, the place names are lettered. In some surveys, however, certain features may not be inked. For example, if the photographic image of all roads is pronounced, they do not need to be inked.

If photobase map sheets are used as field sheets, the inking can be done on transparent overlays. As many as three overlays can be used: one for culture and drainage, one for soil boundaries, and one for symbols. Together these form a composite overlay and can be used in printing the final map. The individual overlays can be used in printing special purpose maps. Adhesive-backed, clear stripping film with printed symbols can be applied to the overlay to save handwork.

In inking soil boundaries, a good procedure is to close each boundary within one section of the field sheet. When the boundary of a small area is closed, its symbol is placed as near the center of the area as practical. More than one symbol is placed in areas that extend for long distances and in those that have intricate shapes.

Mapping along the match lines may be left in pencil until the field sheets have been joined.

Soil symbols on all sheets should be positioned to be read horizontally, or as nearly so as possible, when the map is oriented in one direction. Usually, north is toward the top of the map. If an area is too small to contain a symbol, the symbol may be placed outside it and a leader used to indicate the area to which the symbol applies. The leader should be so

FIGURE 4-6

Example of a field sheet.

FIGURE4-7

Rules of Application for the Use of Conventional and Special Map Symbols for Soil Surveys

1. All symbols are black. Symbols other than boundaries, roads, streams, drainage ends, and soil delineations (pen sizes listed below) will be placed on type overlays of project surveys with clear stripping film with adhesive backing (stickup). Pen size 00 is to be used for symbols on field sheets and for map compilation of other surveys with the following exceptions:

Pen size	Symbols
0	Trail and Soil Delineation.
1	Minor civil division, reservation, land grant and limit of soil survey.
2	National, state province, county or parish boundaries, and center line of dams.
2.5	All roads except trails.

2. All the symbols shown on the legend will not be used in a single soil survey. Symbols actually used will be underlined in red during the initial field review. Changes in symbols selected must be approved by the state soil scientist.

3. Ad hoc symbols will be defined in the legend in terms of the specific kind and size of area represented.

4. All mapping unit boundaries are unbroken lines. Enclosed areas of water, double line streams and double line canals are mapping unit boundaries.

5. Single and double line roads, railroads, minor civil division lines, field sheet match lines or neatlines, soil survey area boundaries, single line canals, and levees are not mapping unit boundaries.

6. Areas represented by conventional and special symbols will not be included in the table "Approximate Acreage and Proportionate Extent of the Soils" in the surveys. Acreage for enclosed areas of water more than 40 acres in size; and streams, sloughs, estuaries and canals more than one-eighth of a statute mile in width is given at the end of the table under "water."

7. The following rules apply to symbols for pits, marsh or swamp, and dumps and other similar nonsoil areas:

    a. Areas less than the minimum size delineation being used in the survey area are indicated only by symbols.

    b. Areas greater than the minimum size delineation being used in the survey area are delineated, classified and correlated as mapping units.

8. Where a map scale change occurs in a soil survey area a neatline is used as a boundary. The map scale change is made a part of the joins note parallel to the neatline, e.g. Joins sheet 89 - 1;31680.

9. Proposed roads are not shown. Where the photo image shows a road under construction, represent it on the map as if it were constructed. Interchanges and access and egress ramps to limited access roads are not shown. "Other" roads are shown as necessary for proper orientation of the map.

10. Symbols for schools and churches are centered on the photo image and are not inked to scale.

11. Departure from these conventional and special symbols must be approved by the Director of the Soil Survey Division.

FIGURE 4-7 (continued)

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

CONVENTIONAL AND SPECIAL SYMBOLS LEGEND

Soil Survey Area ____________

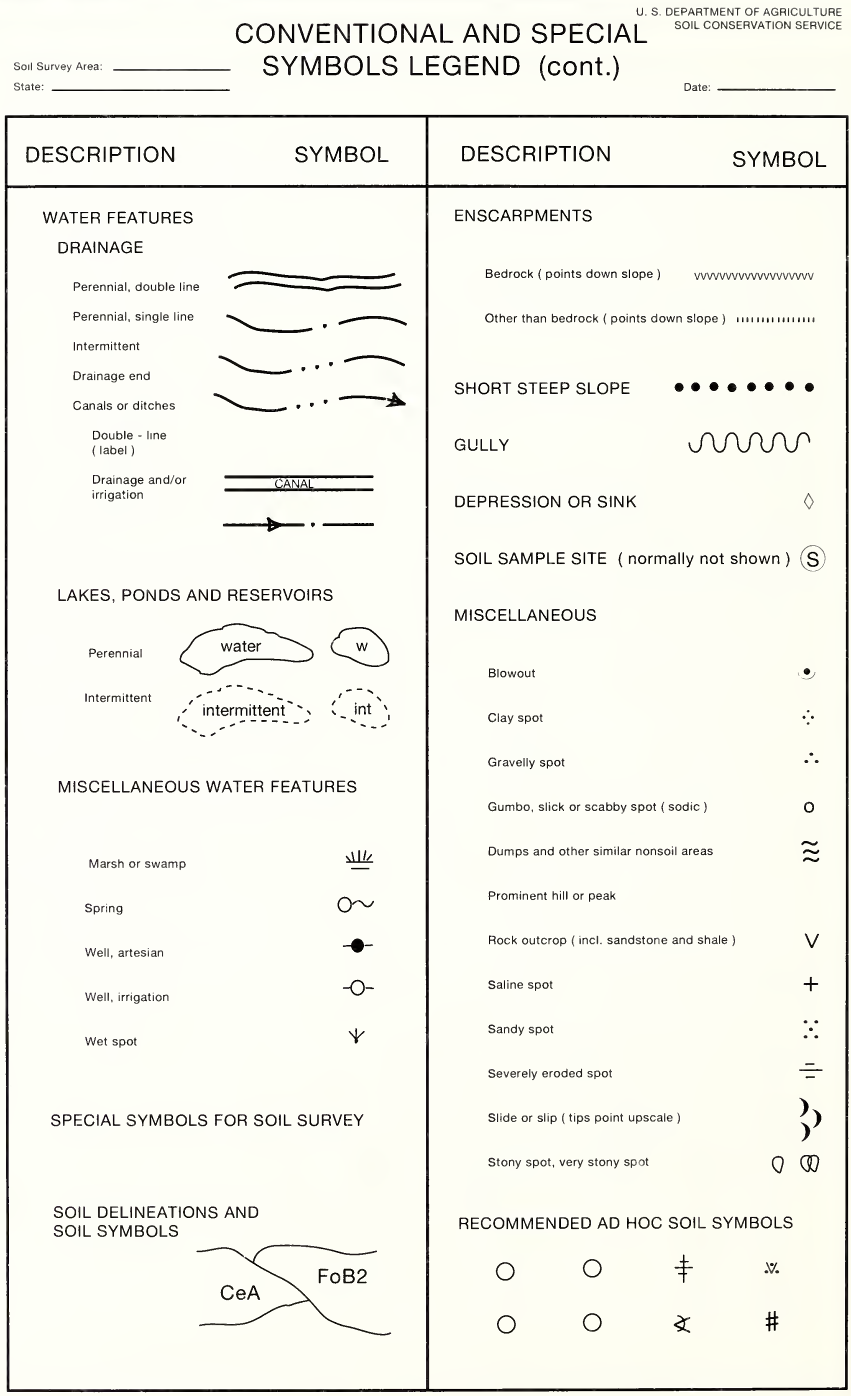
State ____________

Date ____________

DESCRIPTION	SYMBOL
CULTURAL FEATURES	
BOUNDARIES	
National, state, or province	
County or parish	
Minor civil division	
Reservation (national forest or park, state forest or park, and large airport)	
Land grant	
Limit of soil survey (label)	
Field sheet matchline & neatline	
AD HOC BOUNDARY (label)	
Small airport, airfield, park, oilfield, cemetery, or flood pool	
STATE COORDINATE TICK	890 000 FEET
LAND DIVISION CORNERS (sections and land grants)	
ROADS	
Divided (median shown if scale permits)	
County, farm or ranch	
Trail	
ROAD EMBLEMS & DESIGNATIONS	
Interstate	66
Federal	287
State	52
Other	398

DESCRIPTION	SYMBOL
RAILROAD	
POWER TRANSMISSION LINE (normally not shown)	
PIPE LINE (normally not shown)	
FENCE (normally not shown)	x x
LEVEES	
Without road	
With road	
With railroad	
CULTURAL FEATURES (cont.)	
DAMS	
Large (to scale)	
Medium or small	W
PITS	
Gravel pit	
Mine or quarry	
MISCELLANEOUS CULTURAL FEATURES	
Farmstead, house (omit in urban areas)	
Church	
School	
Indian mound (label)	
Located object (label)	
Tank (label)	
Wells, oil or gas	
Windmill	
Kitchen midden	

FIGURE 4-7 (continued)



placed that it cannot be confused with a soil boundary.

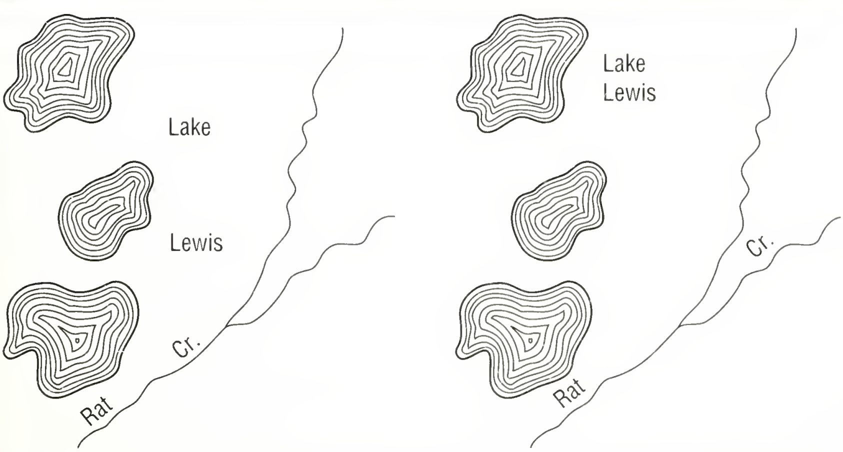
Place names should be inked last so that they may be placed where they will not obscure soil symbols and other details. Place names should be arranged so that they clearly identify their features. Names of features expressed as lines on the map are oriented parallel to the lines. Names of other features are usually oriented horizontally, with north at the top. Important features that serve as landmarks should be named on each sheet. Names of streams should be so positioned that no confusion arises about which branch is meant. Incorrect and correct placement of names are illustrated in figure 4-8.

Neatness and legibility are important in lettering. Maps with many soil symbols, boundaries, cultural features, and the like become confusing unless the lettering is done with special attention to high standards. Every soil scientist should learn the art of freehand lettering.

A simple style of lettering should be used. Freehand styles that use single strokes are best for inking field sheets. The pen is held as in writing and the strokes are made with an even steady motion. Slant or vertical lines are made with a downward stroke: horizontal lines are made with a stroke from left to right. The slant of the letters is kept uniform.

Checking field sheets.—Each field sheet should be checked for open boundaries, areas without symbols, and other errors. Fieldworkers usually check their own sheets, and another person may check each sheet for completeness and legibility. The party leader should be responsible for checking the mapping of each party member. The mapping of beginners

FIGURE4-8



Location of place names. Only the uppermost of the three lakes is Lake Lewis, and Rat Creek is the lower of the two branches.

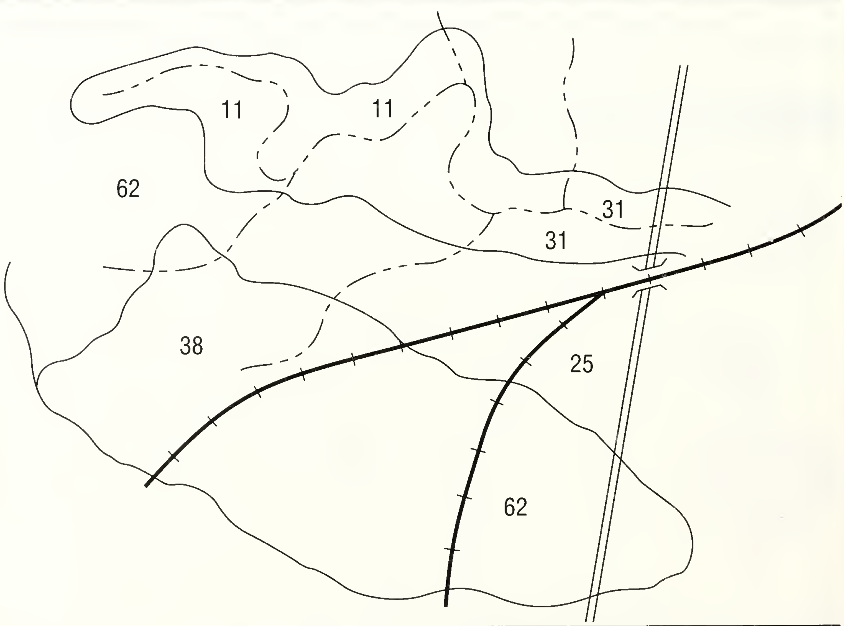
generally needs much checking. If different soil scientists map adjacent field sheets, the party leader can compare their mapping in the areas where the sheets join. During field reviews, supervisory soil scientists responsible for technical standards often check boundaries and symbols on samples of the field sheets of each soil scientist.

After mapping has been completed, the party leader should check all of the field sheets to see if any corrections and remapping are required. Omissions and inconsistencies increase the cost of map construction and delay publication. In order of frequency, the most common mistakes are:

1. incorrect joining at the match-line,
2. failure to close map unit boundaries,
3. omission of symbols or use of symbols not identified in the legend,
4. incorrect interpretation of cultural and drainage features, and
5. use of incorrect place names.

Failure to close soil boundaries is a common error. Figure 4-9 has three open boundaries—between map units 11 and 31, between units 62 and 25, and between units 38 and 62. The person who inked this sheet

FIGURE 4-9



The omission of a map unit boundary is a serious error, as in three places in this sample.

probably overlooked the lack of closure because of the drainage lines and railroad symbols that cross the area. Whatever the cause, the user cannot tell where one unit ends and the other begins. Someone may have to make a special trip to the field to close these boundaries.

Each area of a mapping unit must be separated from all adjoining areas by a soil boundary or the boundary of a body of water. Neither the single lines representing streams nor the conventional symbols for roads, railroads, and the like can serve as map-unit boundaries. Each area also must contain the symbol for only one kind of map unit.

Errors in symbols take various forms. A delineation on a field sheet might be closed without a symbol in it, or a symbol not listed in the legend might be used. Symbols might be illegibly drawn on the field sheet. Practice and care in lettering, good judgement in placing symbols, and care in erasing and reinking mistakes ensure legibility.

Various methods are available for checking field sheets. A good method is to color each delineation by hand on photographic copies of the filed sheets. A color check reviews each delineation and inspects boundaries throughout their length. In another method, each field sheet is divided into sections of perhaps 50 to 100 square centimeters. The delineations within each section are checked one at a time, special care being taken at the edges of the section. If the map checkers are not familiar with the legend, they must be especially diligent in checking the symbols against the legend.

Incorrect placement of drainage or cultural features on the map can seriously reduce the accuracy of map unit boundaries. The location of streams, roads, and the like must be correct. Most errors in placement cannot be checked with precision except by stereoscopic study or field investigation. If accurate reference maps are available, locations of features on the field sheets are checked against them. If possible, locations are checked while mapping is in progress. Place names are verified with an authoritative source.

Keeping records of field sheets.—Each field sheet may be identified by a number that locates it on an index map of the area. The index map outlines and identifies all of the field sheets of the survey. Where single-lens aerial photographs are used, several hundred individual sheets are required and a systematic means of identifying their locations in the survey area is needed. Photographic indices are available for most areas where photographs are used. An index map can be made from a small-scale map by plotting the match-lines of the field sheets.

Each field sheet should contain the name of the survey area, the State, the date of the survey, and the names of the soil scientists who mapped that sheet. Names of others who inked or checked the sheet and

its scale may be given also. Commonly, all this information can be put only on the back of the sheet. If it can be put on the front, it may be placed so that it will appear on photographic copies. A stamp can be used to provide spaces for the information.

The adjacent field sheets are identified on the margins of each sheet. When adjacent field sheets have been joined, the margins of the field sheets may be marked and initialed by the persons responsible. The joined match lines can also be marked on a transparent overlay over the map index.

Measuring the areas of map units.—Soil maps show both the location and the extent of map units. Measurements of the area of each map unit are needed. Planners, for example, need to know the extent of areas that have certain potentials or problems. Processors of farm products frequently need to locate areas that are suited to growing a certain crop. The data on an area are used to help decide whether certain map units of small extent are important enough to be retained on the published map. Measuring the areas also checks the map for open boundaries, delineations without symbols, and unidentified symbols. Measurements on field sheets are subject to errors caused by distortion of the photographs.

The area of map units can be measured for the entire survey area; or sample areas can be selected and the extent of map units in them measured and expanded to represent the entire area.

The accuracy of the estimate, based on sample areas, depends on the size of the sample and where the sample areas are located. If the sample is less than 5 percent of the total area, estimates are subject to relatively large errors. Generally, the sample should be at least 10 percent of the total area. Even with this large a sample, map units of small extent are likely to be either missed entirely or overestimated. The estimates of extensive map units by sampling methods are likely to be reasonably reliable. Estimates based on sample areas can be satisfactory for most uses of data for the major soils in the survey area.

If a sampling procedure is used, dividing the area surveyed into soil associations and sampling each association separately is helpful. The most accurate estimates can be derived from sample strips running all the way across each association and oriented at right angles to the prominent unit boundaries. The strips can be spaced to provide the needed sample size. Square areas and rectangular areas oriented at random yield less accurate estimates, especially if the sample is small.

Several methods can be used for measuring the area of map units. The *dot-grid method* uses a transparent sheet or card on which dots are evenly spaced vertically and horizontally. Each dot on the grid represents a small square, which has a unit area. The transparent sheet is

placed over the map and the dots in each delineation are counted. Dots that fall on the boundary of a delineation are alternately counted. The dots in each delineation are summed for the map unit. The land area represented by each dot can be calculated on the basis of the map scale and the spacing of the dots. Less extensively used are grids that have a network of small squares instead of dots. The squares that fall within a delineation are easily counted. Squares that fall on a boundary of a delineation are averaged during counting. The averaging depends on the judgment of the person who is counting. If it is carefully done, the use of squares can result in somewhat greater accuracy than the use of dots. The former method is more time consuming.

The dot-grid method is simple, inexpensive, efficient, and convenient. For these reasons, it is the method most commonly used in field offices. A short-coming of the dot-grid method is that it is not well adapted where there are long, narrow delineations on the map. It is sufficiently accurate for most purposes, however, because the land areas for the map units tend to be averaged if large areas, that is, entire field sheets, are measured. The *electronic area calculator* is an alternative method to the dot-grid method in that it electronically counts squares on a grid. By using an appropriate grid to fit the desired map scale and a wired pencil assembly to trace the map unit boundary, area can be determined easily from a numerical display. This method compares closely in accuracy to the dot-grid method but is much quicker and more convenient. It is initially much more expensive than the dot-grid method.

The *planimeter* is an instrument used to measure area by measuring the length of the boundary of the delineation. This is done by following the outline of the delineation with a tracer. The value indicated on the planimeter is converted to land area by using an appropriate conversion factor related to map scale. The use of the planimeter is an accurate method to measure maps, but it is very slow and tedious. Accuracy depends on the skill and patience of the operator and on the care taken to convert measured value to land areas.

Computer-based digitizing systems have the capability for measuring the area of map units. These systems are not only very accurate but serve as an excellent final check for errors on field sheets—open boundaries, areas without symbols, and the like. They can replace color checks and other methods of checking field sheets.

Cultural Features

The various mapping agencies of the United States Government have agreed on standard symbols for most cultural and natural ground features that are commonly identified on maps. Most of the symbols used

on soil maps follow these standards. Some soil maps show special features that are not included in the standard list. The symbols for these must be compatible with symbols used by other mapping agencies. Different symbols are not used for the same feature, nor is the same symbol used for different features.

Conventional and special map symbols must be functional and readily identifiable on the map.

Conventional signs and symbols used in soil mapping are shown on figure 4-7. Some of these are described in the paragraphs that follow.

Boundaries of cultural features are shown on soil maps by standard conventional symbols. These include the boundaries of nations, states, counties or parishes, minor civil divisions, reservations (including Federal or State parks and forests), land grants, parks, and cemeteries.

U.S. Geological Survey (USGS) maps are the primary source of cultural boundaries. Where USGS maps are not available or must be supplemented, local sources are used. County or State assessors, planning and zoning officials, and reservation superintendents are authoritative sources. Boundary monuments are located in the field and boundaries are plotted during soil mapping only where boundary location cannot be plotted accurately from references. Boundaries are verified as a precaution against errors.

Where cultural boundaries of different classes coincide, the symbol of the major subdivision is used, for example where a State boundary coincides with a county boundary the State boundary has priority. Where a boundary obviously follows a stream or road for a short distance, the boundary symbol may be omitted. In some places, the road or stream may be labeled for clarity: "Road is county boundary" or "State boundary is center line of stream."

Township and range numbers are shown along the margins of field sheets for all lands that have been sectionized. Section lines are not shown. In some surveys all sections corners are shown; in others, only those that have been located are shown. In a published soil survey, section numbers are printed in the approximate center of each section. Published topographic quadrangle maps show the land grid, though some old ones may need correction. Soil scientists working in an area should be familiar with the local land survey system and its intricacies.

Cemeteries are outlined to scale on field sheets using dashed lines. The name is usually placed within the outline of a large cemetery and outside a smaller one, although the smallest cemeteries are usually indicated by a cross and not named. A feature such as a road or stream may serve as a boundary for a cemetery.

The identification of *airports* and *landing fields* is optional on field

sheets. Boundaries of large municipal, commercial, and military airports and landing fields are shown by the symbol for a reservation. The runway pattern is not delineated if it is apparent on the aerial photograph. Small airfields can be shown by a dashed line symbol similar to that used for a cemetery, or the symbol for a "located object" can be used and labeled. Each airfield that is identified is labeled by its proper name or "airfield," if the name is not known.

Roads are identified on soil survey field sheets by symbol or name. In towns and cities only major roads are identified. Standard emblems are used to designate interstate, Federal, State, and other roads. Route numbers are placed in the emblems. If roads are shown, a simple and explicit classification is used.

The mapping of *trails* depends on their importance for proper map orientation and the help they will provide in locating specific areas on the map. In sparsely settled areas having few readily observable landmarks, important trails are shown and named. In more densely populated areas where roads are common, trails generally are not shown.

Railroads are shown on field sheets by conventional symbols. They may be labeled "railroad" or by the name of the line. Electric trolley lines both in urban areas and beyond city limits are shown by the standard railroad symbol and designated by operating name and type. In large railroad yards with parallel spur tracks and switches and sidings alongside single tracks, only the main track is shown.

Pipelines are shown on soil maps if they might be important as landmarks. A pipeline crossing a remote section of a survey areas may be important. A similar pipeline in a populated area may be difficult to locate accurately and may have little value as a landmark. If shown, a pipeline must be accurately located.

Trunk *power-transmission* power lines are normally not shown on field sheets unless they have value as landmarks. They must be individually evaluated. Lateral distribution systems are not shown. The symbol for power-transmission lines, if used, begins and terminates at towns, power stations, and survey area boundaries.

Levees are indicated by short ticks. If a road or railroad is on the levee, the ticks extend from both sides of the road or railroad symbol.

Large permanent *dams* are shown to scale on field sheets. Thin lines are used to delineate the base of the dam. Smaller dams are indicated by single, heavy lines. A road following the top of a dam is shown in its correct place, and the road line on the upstream side is thickened to represent the dam. A dam symbol is inked to its scaled length. Important dams are named.

Permanent buildings.—rural dwellings, public buildings, and farm

homes—are shown on most published soil maps but are optional. In some areas, buildings are constructed so rapidly that the map is out of date before it can be published. In such areas, omitting symbols for all buildings other than churches and schools is best. In most soil surveys, churches and schools are shown on the published map and may be named.

Symbols for individual houses are commonly not shown in urban areas. Prominent landmark buildings—large schools and large churches—may be shown, but they are not drawn to scale and are identified by the conventional symbols.

The cross or pennant of a church or school symbol is oriented at right angles to a nearby roadway. A building used as both a school and a church is marked by the school symbol. If churches or schools are omitted from large urban area but mapped in rural areas, the notation "omitted in urban areas" is made on the legend of conventional symbols.

Open pits, mines, and *quarries* smaller than the minimum area for delineation are shown only by conventional symbols. Larger areas are delineated, classified, and correlated as kinds of soil or miscellaneous areas.

Producing *oil* and *gas wells* may be shown. Where the number of wells is so large that the symbols are closely spaced on the map, the approximate outline of the field may be shown by dashed lines and the delineated area identified as "oil field" or "gas field" without the conventional symbol.

Streams and *rivers* are shown on the field sheets, and perennial and intermittent streams are clearly differentiated. The pattern of drainage and the classification of the drainage must be complete. If the main drainage courses are identified by stereoscopic study of aerial photographs, the lines must be confirmed and the drainage classified in the field. Most distinct drainage courses more than 1 cm long on the field sheets are shown. Drainage courses are mapped to scale if wide enough to be shown legibly or by single lines if narrow.

A *perennial stream* is one in which water flows constantly except during periods of unusual drought. That a stream is perennial must be verified, especially in semiarid and arid regions where the water in streams and waterholes is vitally important.

Mapping large rivers that change course and width from time to time is difficult. The shorelines shown on a soil map generally mark the areas covered with water for so long that little or no vegetation grows during low water and unvegetated riverwash persists from year to year. Areas that are covered by flood water for only short periods are excluded. Areas that are uncovered only during very low water stages are included.

The level of river stages varies widely, depending on characteristics of the river in relation to the climate of its watershed and other factors.

Where the flow of rivers, though active for brief periods, dwindles or ceases altogether for many months, the normal stage is very low. Thus rivers, such as the Platte and much of the Rio Grande, are normally braided, and the boundaries of the river are usually placed at the outer limits of the area of braided channels. Unstabilized sediment that is washed and rewashed and supports little or no vegetation but persists from year to year may be identified as riverwash. Areas within a flood plain that can support vegetation are shown as soil.

Some streams, especially in areas underlain by limestone, enter abruptly into caverns and may flow for long distances through subterranean channels. The points where the streams enter and emerge are located accurately, but only the surface drainage is shown.

An *intermittent stream* is dry each year for extended periods, usually for more than three months. In arid and semiarid regions especially, intermittent streams are distinguished from perennial streams because they are not reliable sources of water.

Poorly defined water courses are not shown. Aggraded flats or valley floors without well-defined stream channels or scars are shown as soil.

Canals and *ditches*, whether for navigation, irrigation, or drainage, are plotted to scale if they are wide enough. Otherwise they are shown by the single-line symbol. Arrows indicate the direction of flow. Generally, both the main ditches and important laterals of irrigation systems are shown. Large canals and ditches are named on the field sheets if they have names. On the map, canals and ditches must be distinguishable from roads.

Lakes, *ponds*, and *reservations* are delineated to scale on field sheets. The boundary marks the normal water level, which may not be the shoreline observed and recorded at the time of the survey. Normal water level may be marked by a line of permanent land vegetation, but many lakes are bounded by wave-washed beaches above the normal water level. Many reservoirs are bounded by areas that are submerged when the water level is high. The shore line that is evident on aerial photographs may be used to delineate the normal stage of a lake, pond, or reservoir. If a high water level other than wave-washed beaches can be identified, it is shown on the map by the intermittent water symbol and is identified. The area between high water level and normal water level can be defined as a soil map unit if the area warrants it. The intermittent water symbol is not used in these areas. The intermittent water cover is described in the map unit description.

Reservoirs surrounded by an impounding structure are outlined. Some reservoirs have flood-pool lines that are determined from available sources. They are shown on the map by a dashed line and given an

appropriate label, such as "approximate flood-pool line."

The shoreline of an island is determined at the same water stage as the adjoining mainland shoreline. Islands exposed at a lower stage are not shown.

Tidal shorelines present special problems. The mean high tide level (determined excluding the semimonthly highest tides) can be used where the land rises to elevations well above high tide within a short distance from the shore. Where broad marshes mark the transition from sea to land, the shoreline is the outer boundary of the area that supports plants. The soil boundaries extend to that line.

The shoreline of a body of water is not broken for wharves, piers, and similar structures that may be built over the water. Seawalls and retaining walls that are part of a shoreline are shown as the shoreline.

Intermittent lakes are shown on the field sheets as kinds of soil or miscellaneous areas. The dashed line symbol shows the area covered by water part of the year.

Marshes and *swamps* are mapped as soil unless they are too small to be delineated. If too small, they are shown by the conventional marsh or swamp symbol.

Springs are shown on the soil map if they are important in the area. Springs of all kinds are shown in arid and semiarid regions. In humid regions, only large and dependable springs are shown. Some springs have names, which may be printed on the soil map. In arid regions, intermittent springs or springs that have salty or otherwise impotable water are so identified by notes on the map. Walled-in springs are shown by circles, like those for wells. A spring that is a source of a stream is shown by a circle where the stream symbol starts.

Artesian wells and *wells for irrigation* are shown on soil maps where they are important sources of water, as in arid and semiarid regions. Artesian wells are designated by a conventional symbol, whether or not they flow at the surface. In regions of few wells, all are shown; but in thickly settled areas that have many nonflowing artesian wells, they can be explained in the report without being shown on the map.

A *wet spot* is an area of wet soil that is too small to delineate. It is usually somewhat poorly drained or wetter and at least one drainage class wetter than the soil around it. Wet spot symbols are not placed within areas that are mapped as a wet soil.

Special symbols are used to identify small areas of various kinds of soil, miscellaneous areas, and special soil features. These are commonly used for areas that are too small to delineate but large enough to significantly influence use and management. If a specific kind of area is shown by special symbols, all such areas of that land are shown; the symbols

are not to be used haphazardly. The symbols must be defined in terms of the kinds and size of areas each symbol represents.

In some places, the pattern of mappable areas is so complex that symbols and leaders clutter the map. Special symbols used with moderation reduce the congestion of lines and symbols, although many special symbols in a small area reduce legibility. It may be preferable to map as complexes many areas of intricately associated kinds of soil.

Special symbols show relief features that are too small to show as map units; for example, *bedrock escarpements*, *short steep slopes*, and *gullies*. Natural depressions or sinks such as those common to limestone areas, may be shown by the *depression or sink* symbol. Small areas of *rock outcrop* in an area of otherwise deep soil are obstacles to tillage and should be shown. In addition, small areas of *saline* soil and *very stony* soil, in areas otherwise suitable for crops should be shown. Special symbols are used for small areas of some kinds of soil that contrast sharply with surrounding soils in their management needs or productivity, even though they are suited to the same uses. Small areas of *gravelly* soil in gravel-free areas, *sand spots* in areas of finer textured soil, and small areas of severely or moderately eroded soil in areas of noneroded soil are examples.

Equipment

The efficient operation of a soil survey requires the use of certain kinds of equipment, some easy, some difficult to obtain. There are three major kinds of needs: Tools to examine the soil profile and soil testing, measuring and recording devices for mapping, and transportation vehicles. Some of these are described in the following section.

Tools for Examining the Soil

A soil scientist examines the soil often in the course of mapping. Examination of both horizontal and vertical variations is essential. The most commonly used tools are spades and soil augers. Backhoes, spades, and shovels are used to expose larger soil sections for examinations, sampling, and photography. Augers are used in most areas for routine mapping. In some areas, however, a spade is used to examine the soil. In soils free of rock fragments, probes provide samples that are quick and relatively easy to obtain. Where a probe or auger is regularly used for examining the soil, some profiles need to be exposed in a pit and examined as a check. Power equipment is often used to save time and effort. Various small instruments can also be used to examine the soil.

Spades, shovels, picks, and bars.—Especially after a preliminary excavation has been made, a flat-bladed, square- pointed spade is most con-

venient for collecting samples. The best spade for ordinary use in mapping is a tile spade or a post-hole spade that has been modified by cutting off the sharp corners. A tile spade has a rounded point and tapers at the end. It is superior to a post-hole spade for stony and gravelly soils. The blades of post-hole and tile spades are commonly 30 to 45 cm in length. Where deep holes are required, a long-handled spoon-type shovel is useful.

A heavy crowbar and/or pick may be needed to penetrate dry, cemented, or compact layers. A mattock is especially useful for making holes in soils that are hard, dry, stony, or gravelly. A small army-issue trenching pick will serve satisfactorily in some soils, but commonly the heavier conventional mattock with a long handle is better. One end of the mattock is pointed and the other is a chisel. For moist soils and those containing many woody roots, the chisel point is useful; for dry soils, the sharp point is more effective. A geologist's hammer, one end of which can be used as a pick, is also useful in examining rocks and the soil in cuts.

A post-hole digger is useful in removing deep soil material for examination. A digger is heavy and is used mainly for sampling at the bottom of pits where digging is difficult. It removes the soil with less disturbance of structure than most kinds of augers.

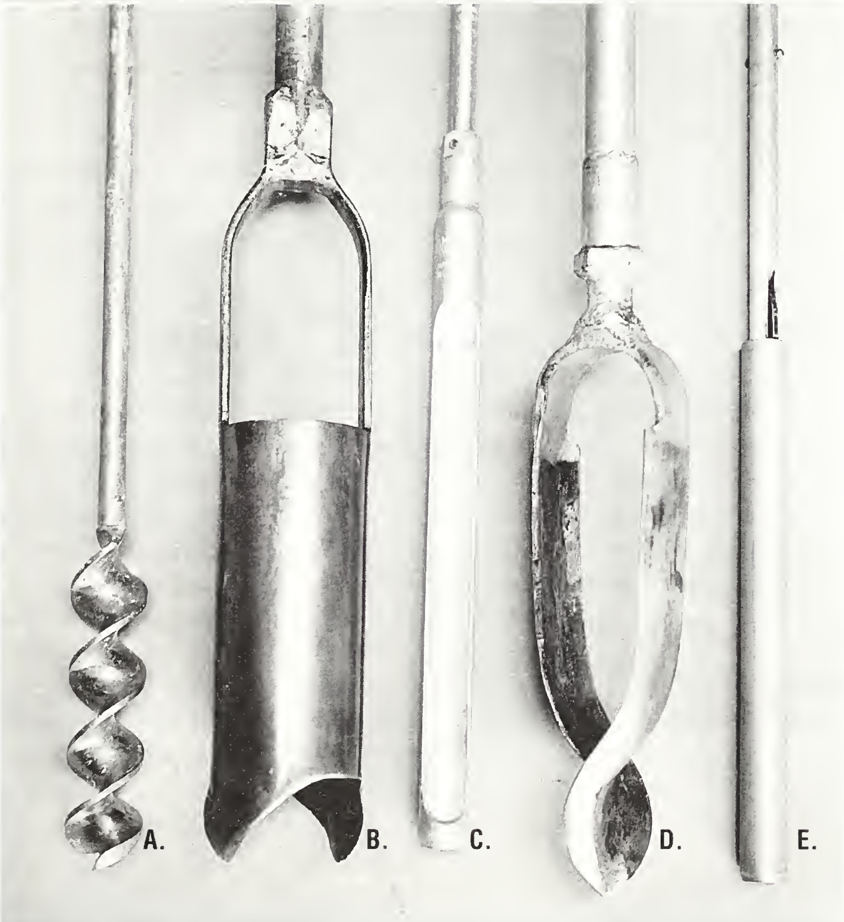
Augers.—The screw, or worm, soil auger is essentially like a wood auger and ranges from about 2½ to 4 cm in diameter (fig. 4-10a). The worm part is about 15 cm in length, and the distance between flanges is about the same as the diameter. If the distance between flanges is less, removing the soil with the thumb is difficult. In clayey soils, a bit of 2 ½ cm may work better than the larger ones. The shaft is commonly 100 to 150 cm in length. Extra lengths can be added for deep boring. The bit will become tapered as it wears, therefore, it should be replaceable. A scale can be marked on the shaft of the auger to measure depth to the tip.

Screw augers made especially for examining soils are available, but they can also be made from a wood auger bit and lengths of pipe. The auger bit is welded to a steel rod or iron pipe with a crosspiece at the top for a handle.

A screw auger is easily carried. It can be used to examine gravelly or stony soils and to bore holes rapidly. It cannot be used in dry or sandy soil because the soil material will not adhere to the bit. It is difficult to pull from the bored hole. The extracted soil material is disturbed more by a screw auger than by other augers and probes.

Several kinds of barrel augers are used. Barrel augers are known as post-hole augers, bucket augers, orchard augers, core augers, and various other names. They have a cylinder, or barrel, to hold the soil, which is forced into the barrel by cutting lips at the lower end (fig. 4-10b). The

FIGURE 4-10



Soil augers and tubes: *A*, screw or worm auger; *B*, barrel auger; *C*, sampling tube; *D*, "Dutch""mud" auger; *E*, peat sampler.

upper end of the cylinder is attached to a length of pipe with a cross-piece for turning at the top. Although both ends of the cylinder are open, the soil generally packs so that it stays in place while the auger is removed from the hole. A few taps of the cylinder on the ground or on a board will loosen the soil for removal. Barrel augers with special closed cutting blades are available for use in sandy soils, very wet loose soils, and very dry soils. Tips should be made of hardened steel to resist wear.

Barrel augers disturb the soil less than screw augers. Soil structure, porosity, consistence, and color can be observed better. Barrel augers work well in loose or sandy soils and in compact soils. They are not well

suited to use in wet or clayey soils, though an open-sided barrel is available that works well. They also work poorly in stony and gravelly soils. Barrel augers bore more slowly than screw augers or probes. Generally, they are more bulky to carry. They are easy to pull from the hole. Tips wear excessively if not made of hardened steel. Where animals are grazing, the holes must be filled.

The Dutch auger is a modified barrel auger having two connected straps with lips (fig. 4-10d). The cylinder is about 5 to 10 cm in diameter. The cutting blades are so constructed that the soil is loosened and forced into the cylinder of the auger as it cuts into the soil. The Dutch mud auger works well in moist or wet soils of moderately fine or fine texture. This auger works poorly in other moist or wet soils and in all dry soil.

Soil augers are simple in design and somewhat crude in appearance, but considerable skill is required to use them effectively and safely. They must be pulled from the soil by using a technique that puts stress on the leg muscles, rather than the back muscles, to avoid serious back injury. Twisting the auger firmly while pulling takes advantage of the inclined plane of the screw to break the soil loose. A pair of pipe wrenches is needed to add and remove lengths of shafts and bits.

Examinations of deep deposits of peat are made with special tube-like samplers. A peat sampler designed by the Macaulay Institute for Soil Research, Aberdeen, Scotland, takes a relatively undisturbed volume that can be used for measurement of bulk density. The Davis peat sampler, consists of 10 or more sections of steel rods, each 60 to 120 cm in length, and a cylinder of brass or Duralumin, approximately 35-cm long with an inside diameter of about 1.9 cm (fig. 4-10e). The cylinder has a plunger, cone-shaped, at the lower end and a spring catch near the upper end. The sampler is pressed into the peat until the desired depth for taking the sample is needed. Then the spring catch is released, allowing the plunger to be withdrawn from the cylinder. With the plunger withdrawn, the cylinder is filled by forcing it further downward. The cylinder protects the sample from contamination and preserves its structure when the sample is removed. With this instrument, one can avoid the error of thinking that firm bottom has been hit when actually a buried log is encountered.

Probes.—Probes consist of a small-bore tube that has a tempered sharp cutting edge slightly smaller in bore but larger in outside diameter than the barrel (fig. 4-10). Approximately one-third of the tube is cut away above the cutting edges so that the soil can be observed and removed. Probes are about 2.5 cm in diameter and about 20 to 40 cm in length. The tube is attached to a shaft with a "T" handle at the opposite end. Shaft length can be varied by adding or removing sections. Probes

can be used to examine the soil to a depth of 2 meters. A pedal that is attached to the shaft is available to allow the operator to apply body weight. Some workers carry rubber or plastic mallets to drive the tube into the soil. A pair of pipe wrenches is needed to add and remove lengths of shaft.

Probes work well in moist, medium textured soils that are free of gravel, stones, and dense layers. Under these conditions, the soil can be examined faster than with an auger. Probes are very difficult to use in dry, dense, or poorly graded soil, and in soil containing gravel or stones. Probes disturb the soil less than augers, but they retrieve less soil for examination. Probes are light and easily carried, and they pull from the hole more easily than screw augers. Often a special punch or dowel must be used to clear the tube. Use of a soil probe is the fastest method to collect samples of surface layers for analysis. Probes used with power equipment have wide applications in soil surveys (fig. 4-11).

Power equipment.—Power equipment is used for rapid excavation or for extracting cores and samples rapidly and from depths that are difficult to reach with hand tools. The use of power equipment results in large savings in time and permits deeper and larger excavations with better exposure of the various horizons than can be attained with hand tools. Not all sites, however, are accessible to power equipment. Most of

FIGURE 4-11

A pickup truck with a power probe and a tool compartment mounted in the back. Two sizes of probes and an extension rod are illustrated.

this equipment is powered by the motor of the tractor or truck on which the equipment is mounted, although some of the heavier types have separate power units.

A backhoe (fig. 4-12) is used to expose vertical sections of soil. The width of the bucket, or shovel, ranges from 30 centimeters on the smaller models to more than 75 cm on the larger ones. Small backhoes are available that mount on the back of small trucks or on small self-propelled vehicles. The larger backhoes are mounted on tractors. Excavations can be made rapidly to depths of 2 or 3 m performing in a matter of minutes a task that would take two people most of a day. Backhoes can be used effectively in gravelly and stony soils as well as in soils that are stone-free. They ensure good horizontal and vertical exposure of the soil profile.

Backhoes have limitations. Maintenance costs are high, and time must be taken for maintenance. Operators must be trained, and safety standards must be met. Some property owners do not want large equipment on their property. There is a tendency to dig pits so deep that site walls are weakened. This practice is dangerous for anyone in the pit. Rental costs for backhoes are high in the areas where machines are available for rent.

Power augers are commonly mounted on a small truck and are powered by the engine of the truck. Some have independent power plants and can be mounted on a trailer. The auger can be raised to permit soil to be taken from the bit for examination and can be reinserted in the

FIGURE 4-12

A backhoe mounted on the rear of a small tractor.

FIGURE 4-13

A power-auger mounted on a pickup truck.

hole for continued sampling. The bits are 5 cm to more than 15 cm in diameter and generally are threaded over lengths of 50 cm or more. Some augers, such as that in figure 4-13, are threaded their entire length and have extensions that permit sampling to depths of a few meters. Power augers can be equipped with barrel-type bits. The barrels are usually larger and heavier than those on hand augers. Most power barrel augers have a cylinder that can be opened for removing the sample.

Power-operated probes (figs. 4-11 and 4-14) are used in moist soils that have few stones. They are usually mounted on a truck and are forced into the soil by hydraulic drivers that are powered by the engine of the truck and act against the weight of the truck and its load. The tubes are usually 2.5 to 10 cm in diameter. They can effectively remove undisturbed cores of soil to a depth of 2 m or more. The top of the tube can be taken off. The tube is open on one side, which permits removal of the core. Power probes are especially useful in moist stone-free soil material, such as loess. They function poorly in dry soils and in soils having cemented layers.

Equipment is available that anchors the truck to the ground by means of a screw. Anchoring allows undisturbed cores to be taken at a greater depth and over a larger range of soil conditions.

Power equipment for extracting samples for examination or analysis is necessary in soil surveys that require systematic sampling of deep lay-

FIGURE 4-14

A hydraulically operated sampling tube mounted on a pickup truck. The open-faced tube is in place. Hydraulic controls are at the right.

ers, as in many areas where landscapes have low predictive value. In dry areas, deep layers that have no influence on present vegetation can be very important to the success of irrigation farming. Power equipment has made surveys of such areas much more accurate and much less physically demanding on fieldworkers.

Power augers and probes have limitations. Generally, holes can be bored or probed only when the truck is level. If the truck is not equipped with four-wheel drive, off-road operation in wet areas is curtailed. Fences further restrict off-road movement. Equipment and maintenance costs of power augers and probes are high. Operators must be trained and safety standards met. Power augers mix the soil so that depths to different layers cannot be measured accurately.

Dense soils and soils that contain large amounts of rock fragments are difficult to examine. Electrically powered jackhammers that quickly loosen compact or skeletal material are available. The loosened material can be thrown from the pit with a shovel. The jackhammers are similar to those used in street repair. A chisel bit is used. The power source is the truck generator or an independent gasoline-powered generator. Use of jackhammers is limited to areas that can be reached by truck. The initial cost is high.

The scheduling of power equipment is important to ensure maximum use of it while the equipment is available and weather and soil-

moisture conditions are advantageous.

Small implements.—Many kinds of small implements are used for examining soil. Although personal preferences may influence choices, certain general types of implements are essential almost everywhere.

A large knife is the most commonly used small tool for probing and digging in an exposed profile. A sheath knife having a blade about 10 to 15 cm in length and 2 1/2 to 5 cm in width—the kind available for hunting or camping—can be used for probing the soil, for cutting through peds to observe the interior, for removing small amounts of material, for cutting roots, for scraping the vertical or horizontal sections of the pedon, and for a variety of other purposes. Trowels, spatulas, putty knives, and other small instruments are used similarly.

A geologist's or mason's hammer is useful, especially for breaking cemented layers and examining rock fragments and very strongly cemented nodules. The chisel-shaped end of the head can also be used for digging unconsolidated material.

Various small instruments for measurement and observation are essential. A scale for measuring is indispensable. Graduated steel tapes that retract into a small case are most useful. A hand lens is very important. A 10X lens is most common, but lenses having magnifications that range from 4X to more than 50X are used. Some, mounted in a pen-sized tube, have high magnification but a small field. Some of these have bat-

FIGURE 4-15

A hand-held map board with aerial photo base map in place.

tery-powered lights for illuminating the sample. A pocket magnet for separating magnetic material is useful in some areas. A soil thermometer is needed by most field scientists. Those having a metal probe and a dial on which the temperature is read are especially suitable for use in soil.

A grid for area measurements or for point counts of features like stones is an important part of the kit of a soil scientist. The grid may be simply a piece of wire mesh with the spacing of wires chosen to fit the scale at which measurements are to be made. A hand tally or counter is useful for point counts; it is also useful for recording paces in measuring distance. Standard color charts and standard charts for the estimation of proportionate area are also necessary components of the kit.

Mapping Equipment

Various small pieces of equipment and instruments are used in mapping. The choices of fieldworkers vary, but certain kinds of equipment are essential.

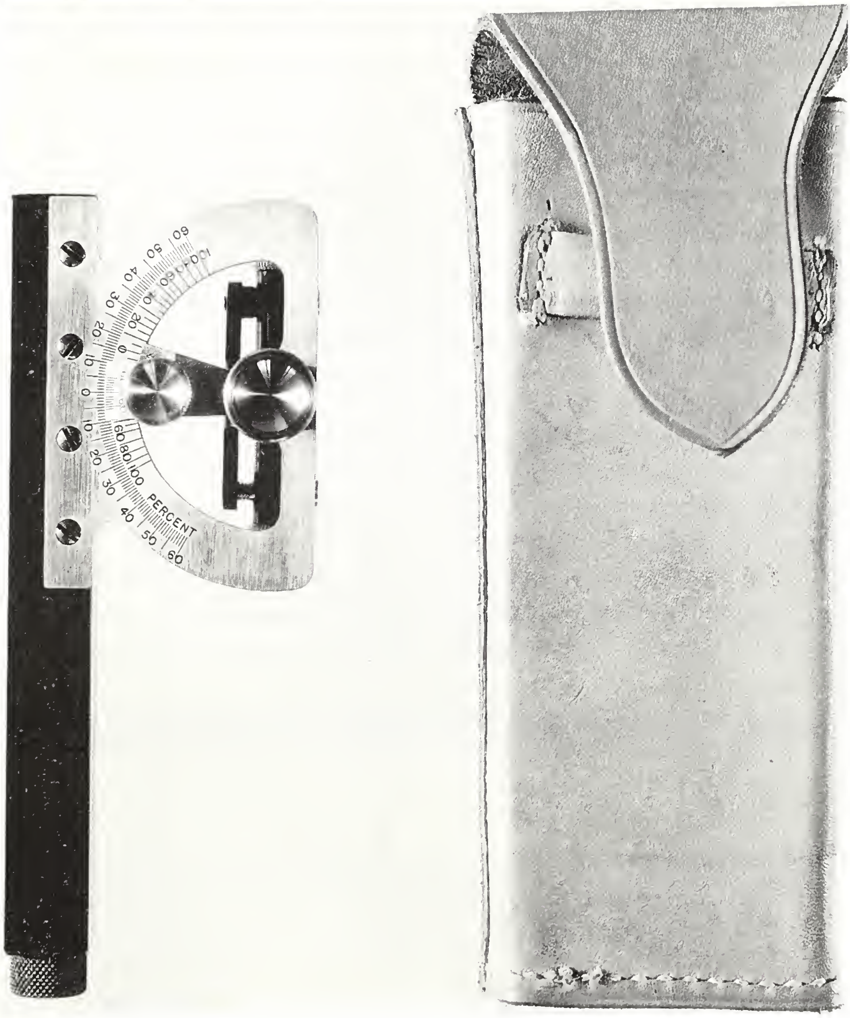
Various kinds of metal or wood clipboards or folders are used for holding the map (fig. 4-15). Some surveyors use an aluminum folder with a spring clip and a covering flap that is hinged at one edge. If the field sheets are large, a rotary map cylinder is useful.

The part of the map being used is exposed on the board, and the unused part is rolled into a cylinder attached to the edge of the board.

FIGURE 4-16

A metal cylinder used to carry large maps.

FIGURE 4-17



Abney hand level with case.

The cylinder protects the unused part of the map and provides a work surface. Some field scientists make these map holders to suit their own needs (fig. 4-16).

The use of aerial photographs as mapping bases has almost eliminated the need for compasses for finding bearings. In areas where keeping located is difficult, a compass must be used to orient the map and to take bearings from which the soil scientist can plot location. A traverse board consists of a map board that has a compass attached at one edge

and that rotates on a tripod.

In mountainous areas, an altimeter can be used to determine elevation and establish location relative to contours on topographic maps. Altimeters measure altitude by measuring changes in barometric pressure as related to elevation and must be adjusted at a point of known elevation to the barometric pressure at the time.

An instrument is needed for measuring slope gradient. The Abney hand level (fig. 4-17) is commonly used. For convenience, the scale is graduated in percent of slope or in both percentage and degrees. This instrument consists of a small spirit bubble level pivoted above a graduated arc and is operated by rotating the level until the bubble, visible through the eyepiece by means of mirrors, indicates that the level is horizontal. The barrel of the level is sighted parallel to the soil surface. The gradient is read directly from the graduated arc.

Clinometers are used in some places to measure slope gradient. In a clinometer, a weighted string swings across a graduated arc. Clinometers are lighter in weight, more convenient to carry, and slightly faster to use than an Abney level.

A scale for measuring distances on the map is needed. A supply of pencils that have different degrees of hardness should be carried. The hardness chosen is determined by temperature and humidity and by the material of the mapping base. If aerial photographs are used, the pencils should leave a fine dark line that does not smudge easily on handling, but it should not be hard enough to cut the emulsion. Because soil boundaries must be adjusted and the symbols changed frequently, the pencils should make marks that can be erased without smudging and without damaging the mapping base.

Transportation

Field operations of the soil survey require transporting workers, equipment, supplies, and soil samples. Vehicles are provided to the soil survey party for their daily operations. The time spent by soil scientists traveling to and from the field is lengthy and mainly unproductive. Enough vehicles are provided to keep travel time as short as possible.

Additional equipment used for special purposes or for short periods is usually rented or supplied as needed. A passenger van, for example, may be furnished by one of the agencies during a field review. Aircraft may be rented to visit areas not readily reached by ground transport.

The uses of vehicles vary widely from one area to another. In some areas, travel is mainly on roads; in other areas, vehicles must be used to travel across country during mapping or to reach remote sites for soil studies. Some vehicles must carry power equipment or pull trailers. All

vehicles that are provided for use should carry workers efficiently and in comfort and safety, hold the equipment that is used regularly, have some reserve capacity to accommodate an extra load, and protect workers and equipment from adverse weather.

In many areas, pickup trucks are desirable. Trucks are available with optional equipment that may be useful in some areas. Optional equipment includes four-speed transmissions for mountainous and off-road travel; four-wheel drive for off-road travel under adverse conditions; high clearance for travel over rough or stony areas; oversize radiators for use in hot climates, for use where the truck engine will be idled for long periods, or for use with power probes, augers, or winches powered by the truck engine; special tires and wheels for unusual wet, rocky, sandy conditions; and special bodies or truck beds for mounting and storing special equipment (fig. 4-11). In some remote areas, vehicles are equipped with two-way radios. The various kinds of optional equipment have various disadvantages and limitations such as increased initial cost, increased operating and maintenance cost, increased downtime for the truck, difficulty in obtaining replacement parts, a decrease in the truck's handling qualities, and a decrease in road speed.

In areas with good roads and little off-road travel is required, passenger vehicles are adequate. Passenger vehicles also are used to trans-

FIGURE 4-18

An example of one type of all-terrain vehicle used for soil survey operations in areas inaccessible to ordinary wheeled vehicles.

port groups for field reviews.

Specialized vehicles are necessary in some areas. Tracked vehicles and all-terrain vehicles (ATV's) may be needed in very rugged areas (fig. 4-18) Marsh buggies with large buoyant tires and airboats are used in swamps and marshes. Snowmobiles provide access in winter to some northern swamps where travel is impossible or impractical in other seasons. Trail bikes or ATV's can be used in areas that could otherwise be reached only by walking. Specialized vehicles must be reliable in relatively inaccessible areas. The equipment must be transported to the use area. Costs of buying or renting the equipment, maintaining it, and training operators can be high. Time is needed for transport, maintenance, and training. Some kinds of equipment are hazardous to operate. Sensitive ecosystems may be damaged by the equipment.

Aircraft, particularly helicopters, are used in some soil surveys to transport workers and equipment and to provide broad views of landscape and vegetation. Aircraft are useful for photographing landscapes, soil patterns, and land use. Availability, cost, and lack of conventional landing sites are the main limitations.

CHAPTER 5 Information Recording and Management

Information gathered during a soil survey of an area is recorded partly on maps and partly as notes. The two methods of recording work together to ensure a quality survey.

Field Notes

Field notes include both information on the behavior of the soils and inferences about how the soils formed. Field notes make up the basic information used in developing the descriptive legend, soil interpretations, and the manuscript of individual soil surveys. The notes are used for preparing standard definitions and descriptions of soil series and for correlating soils in the national program. Field notes are as important as the field sheets on which accomplishments are recorded.

The best notes are those written while observations are fresh. For example, the description of a soil profile is recorded as it is examined. Information from a conversation with a farmer is best recorded during the conversation or immediately thereafter. Unless notes are recorded promptly, information may be lost. All field notes should be clearly identified. The survey area, date, location, and author are necessary on looseleaf sheets and tape recordings. The date and location are needed for each entry in a notebook. Each note should be related to an identified soil. The source of information that is obtained other than from direct observations should also be identified.

Field notes must be understandable to all survey personnel. Shorthand notes need to be transcribed to be useful to others. Only common words and expressions, as found in a standard dictionary, should be used.

The most important notes record the commonplace—extensive kinds of soils and their properties, the common crops, the success of septic systems, and so on. The tendency to record other than the commonplace should be avoided, because subsequent efforts to prepare a

FIGURE 5-1

Recording observations seen in an auger core.

descriptive legend or make interpretations from such notes will be unsuccessful. Field notes should indicate how closely they represent the commonplace. Survey personnel must first learn to see and record the commonplace, then add departures from the usual.

Field notes record observations and complete descriptions of pedons at specially selected sites. Notes that are made during mapping are usually not full descriptions. They may record only color, texture, and thickness of major horizons as seen in auger cores (fig. 5-1). The information is used to supplement detailed examinations. Notes of this kind are especially important for soils that are not well known and for soils of potential, but questionable, map units.

Field notes include information about the relationship of map units to one another, to landforms, and to other natural features. The setting of a soil—its position in the landscape—is important. Landscape features strongly influence the distribution of soils. From the landscape, the properties and extent of the soil and the location of soil boundaries can be deduced. The kind of landform or the part of it that a particular soil occupies and how the soil fits into the landscape should be described. Soil

patterns and shapes of soil delineations are important in relation to large-scale soil management. Landscape identification is discussed in chapters 2 and 3 of this manual.

The kinds and amounts of inclusions in map units, as well as their positions in the landscape, are noted and recorded during fieldwork. The inclusions are either identified by name, or their contrasting properties are described. Although the kinds and amounts of inclusions vary from delineation to delineation, an experienced surveyor has little difficulty in maintaining an acceptable level of interpretative purity within a mapping unit. This is due to the fact that most contrasting inclusions (dissimilar soils and miscellaneous areas) occupy specific, easily recognized positions in the landscape. If a precise estimate of the taxonomic purity of a given delineation is needed, special sampling techniques—line-transects or point-intercept methods—are required (ch. 2).

Notes should be made on soil erosion in particular map units. This could include such items as descriptions of eroded areas, degrees of erosion within and between phases, differences in variability among soils and landscape positions, extent of redeposition in map units, and effect of erosion on crop yields and management of the soil (ch. 3).

Soil behavior concerns the performance of a soil as it relates to agricultural productivity, its susceptibility to erosion, and its performance as a foundation for houses or as a waste-disposal site. Notes on soil behavior, unlike those on nature and properties, are obtained largely from the observations of others. In addition, field scientists record direct observations and make inferences which should be labeled as such.

Notes on behavior focus on the current and foreseeable uses of the important soils in an area. Where range is the primary use of a survey area, information on range production may be needed for all of the soils of the area. Notes on the performance of soils under irrigation, however, would probably be needed as well where the soils are irrigated. Information on probable forest growth might be pertinent to the purposes of the survey even though it comes from the experience of only a few individuals or a few kinds of soils. An area of rapidly expanding population needs data on the engineering performance of soils—how well the different kinds of soils would support houses, what kinds of subgrades are required for streets and roads, and whether onsite waste disposal systems would function satisfactorily.

Valuable information about soils can be obtained from observations made in the field while surveying. Soil scientists can see poor crop growth on a wet soil or on an eroded area. They note the failure of a road subgrade or of an onsite waste-disposal system in specific kinds of soil. On the other hand, data on yields and management practices for specific

crops usually come from farm records or experimental fields. Similarly, information on forest growth is usually derived from observations made by others, but can be supplemented by information recorded by the soil scientist. Most information on the engineering performance of a soil comes from people who work with structures and soil as a construction material. During field work, a special effort should be made to obtain this kind of information from knowledgeable people.

The source of information about soil behavior is evaluated and recorded in the field notes. Inferences are to be clearly distinguished from observations of soil morphology, vegetation, landform, and the like. Most notes about how soils formed, for example, are inferences. The condition of growing crops is observable, but statements about soil productivity based on such observations are inferences. That soil material is nearly uniform silt loam and lacks coarse fragments is directly observed; the conclusion that the soil formed from loess is an inference.

Theories that have been formed on the basis of inference should not unduly influence the choice of observation sites or the properties to be observed.

Form and Storage of Notes

Each field party should devise a simple, easy system for taking and filing field notes. No single way of taking field notes is prescribed, because no standard system necessarily works well in all parts of the country.

Most field notes are handwritten, in longhand or shorthand, and are immediately available for reference. Such notes can be typed later, although typing is seldom necessary if the notes are neat and well-organized.

Portable tape recorders and small computers can be used for taking field notes. Note taking will need to be well organized for this method. The risk of oversight is larger with tape recordings than with handwritten notes because less time is available for reflection when recording the spoken word than when writing notes. Tapes should be played back after notes are recorded. Recorded notes are usually retrieved and typed later for filing.

Photographs are a quick and accurate way to store information. They could be used more often in soil surveys than they have been in the past.

The sizes and formats of the notebooks that are used in soil surveys depend on working conditions and personal preferences. Large notebooks with pages of about 21 x 27 cm provide ample space for writing and sketching. Smaller notebooks, 8 to 13 cm in width and 13 to 20 cm in length, have advantages for a person on foot because they can be carried in a pocket. Loose-leaf notebooks, springback binders, and clipboards are widely used. These permit easy sorting and arrangement, if

notes for only one site or observation are made on a sheet. Completed sheets can be filed at field headquarters every day. For the study of large areas and for reconnaissance trips, small bound notebooks are less bulky and less apt to be misplaced than are the individual sheets. Computers also can be used to store information.

The filing system set up at field headquarters to preserve the information should be as simple as possible and yet allow recovery of the information when it is needed. All withdrawals from the files should be recorded.

In early stages of a survey, a standard filing cabinet with a folder for each map unit is sufficient. Alternatively, descriptions and notes can be kept in binders arranged by map units and taxonomic units. Map unit descriptions and notes are usually filed under series name plus modifiers. A separate folder is provided for notes that apply to the series as a whole. The mechanics are not important as long as notes and descriptions are accessible.

As a survey continues, additional folders are usually needed for soil interpretations, for the various kinds of general information about the area, for photographs, and for miscellaneous notes. Separate folders generally are kept for the specific sections in the soil survey manuscript—geology, vegetation, land use, crop yields, soil suitability, soil potential ratings, and others. As the survey progresses, having the information and notes on each topic in one place becomes increasingly useful, and the notes are transferred to individual files.

Cross-referencing helps in finding notes that include information on more than one subject. For example, a given note may contain both information on the nature of a map unit and on the yields of one or more crops. That note can be placed in the folder for the map unit and a reference to the map unit placed in the file on crop yields.

Much of the information in field notes is summarized in the descriptive legend. Field notes on soil behavior are repeated or summarized in sections of the soil handbook. Although the information in the soil handbook and descriptive legend is readily accessible, not all of the field notes are included. Consequently, the original notes are kept on file.

Field notes and information in the soil handbook and descriptive legend are very useful after publication for evaluation of the soil survey. Adequate notes help soil correlation and interpretation specialists to update an old survey and eliminate the need to completely remap the survey area. This information can be copied and stored in the computer, on microfilm, or on microfiche. Computer disks and microfiche copies are inexpensive and may be very useful to technical staffs. The original paper can then be discarded.

Soil Profile Descriptions

Soil profile descriptions are basic data in all soil surveys. They provide a major part of the information required for correlation and classification of the soils of an area. They are essential for interpreting soils and for coordinating interpretations across State and regional boundaries. The soil descriptions and the soil map are the parts of a published survey having the longest useful life.

Field descriptions of soil profiles range from partial descriptions of material removed by a spade or by an auger to complete descriptions of pedons seen in three dimensions from intersecting pits as horizontal layers are removed sequentially from the surface downward. Most field descriptions of soil profiles are the former, so care in making them is essential.

Field descriptions should include:

- Observed external attributes of the polypedon, such as landform and characteristics of slope;
- Inferred attributes of the polypedon, such as origin of soil parent material and the annual sequence of soil-water states;
- Observed internal properties of the pedon, such as horizon thickness, color, texture, structure, and consistence;
- Inferred genetic attributes of the pedon, such as horizon designations and parent material;
- Inferred soil drainage class;
- The classification of the pedon in the lowest feasible category;
- The location of the site relative to geographic markers and in terms of landscape position;
- The plant cover or use of the site;
- The date, time of day, and weather conditions; and
- The name of the describer.

The degree of detail that is recorded depends on whether the description is intended to provide a complete standard for comparing the other pedons placed in the same taxonomic class or simply to determine the variation of a selected property within a taxon.

The attributes of pedons and polypedons, procedures for describing their internal properties, and standard terminology are described in chapter 3. When standard terms are not adequate to characterize all properties and attributes of a soil, common descriptive words are used to elaborate.

Standard Forms for Soil Profile Descriptions

Standard forms are useful for recording the observations and data required in a soil survey. They permit recording of information in a

small space. Examples of standard forms used for soil profile descriptions, along with some additional information, are illustrated in figures 5-2 and 5-3. These figures are merely examples, because no standard form covers all situations. Furthermore, forms require modification as more is learned about soils and how to evaluate data.

Standard pages or forms can be prepared in different sizes to fit various notebooks. Forms printed on blue rather than white paper produce less glare when used outdoors.

Handheld computers can be programmed, following a standard format, to permit entering soils information while in the field. The information can be downloaded later to a computer in the office. The office computer can be used for storage of information, sorting, and printing out the description.

A standard form serves as a checklist of characteristics that should be recorded. A checklist is especially valuable for beginners because it reminds them to look for at least the listed properties, but observations should not stop with the listed properties. There is a strong tendency to record the information required by the form and then stop. Thus, a form designed to set a minimum on the amount of information recorded also tends to set a maximum. Good soil profile descriptions, however, require information beyond that needed to complete the form.

Standard forms are most useful for recording the day-to-day observations made during mapping. Many such notes are not full descriptions of pedons. These short notes can usually be made on a standard form more easily than they can be written in longhand. Abbreviated notes are also useful in recording many observations during field reviews and when transecting. For these and similar purposes, the forms make note-taking easier and lessen the risk of recording an inadequate description. Complete descriptions of pedons, such as those made when soils are sampled for special studies or those of the typical pedons of soil series, can be written in longhand as block descriptions on a standard form which becomes a checklist.

Notations on forms.—The small spaces on standard forms require that abbreviations or symbols be used for much of the information. Words can be used to identify and describe the polypedon; symbols are needed for internal properties. Many different standard notations have been used. The symbols and codes used by each soil scientist should be documented either (1) by defining the individual's own notations or (2) by referencing a standard document, such as chapter 3 of this manual or the pedon coding system used by the National Cooperative Soil Survey. Individual documentation should become a permanent record of a survey area so that the information can be correctly interpreted by others.

FIGURE 5-2

SOIL SERIES REPRESENTED	DATE MO DAY YR	SITE ID ST COUNTY UNIT	SUB	MLRA	LATITUDE DEG MIN SEC	DIR	LONGITUDE DEG MIN SEC	DIR

SURVEY AREA ID	MAP UNIT SYMBOL	NOTE ID	TRANSECT ID	YIELD ID	PHOTO NUMBER	LAB SAMPLE NUMBER	DESC TYPE	PED ON TYPE	CORRELATED NAME

%	SHP U A	G H M S	ASP. DEG.	SLOPE LENGTH ABOVE TOTAL	MICRO K A P	POS	PHYS MAJ LOC	O	SO	GG	SG	PSC	MIN	RX	TMP	DTH

PRECIP	WATERTABLE DEPTH DAYS	KD	LU	ST	HC	DR	ELEVATION	PARENT MATERIAL 1 W B M ORIG	2 W B M ORIG	3 W B M DRIG	4 W B M DRIG	BDRX

TEMPERATURES °C AVERAGE AIR ANN SUM WINTER	AVERAGE SOIL ANN SUM WINTER	MST RGE	WEATHER STATION NO	CONTROL SECTION PSC	ER WA	RN OF

DIAGNOSTIC FEATURES DEPTH	KND	DEPTH	KND	DEPTH	KND	DEPTH	KND	DEPTH	KND	FLOODING FRQ MD DAYS	PONDING FRQ MO DAYS

VEGETATION SPECIES				
1	2	3	4	5
6	7	8	9	10

GEOGRAPHICALLY ASSOCIATED SOILS	
1	2
3	4

DESCRIBERS NAME

LOCATION DESCRIPTION

NOTES

Soil description form.

FIGURE 5-2 (continued)

	DEPTH UPPER / LOWER	HORIZON DESIGNATION (DISC, MASTER LETTER, SUFFIX)	VOL % LAT / TOT	THICK-NESS AVE(a) / MAX(b) / MIN(c)	DRY COLOR LOC	DRY COLOR %	DRY COLOR HUE	DRY COLOR VAL	DRY COLOR CHR	MOIST COLOR LOC	MOIST COLOR %	MOIST COLOR HUE	MOIST COLOR VAL	MOIST COLOR CHR	TEXTURE CLASS	TEXTURE MOD
1				a b c												
2				a b c												
3				a b c												
4				a b c												
5				a b c												
6				a b c												
7				a b c												
8				a b c												
9				a b c												
10				a b c												

FREE FORM NOTES

Soil description form (continued).

FIGURE 5-2 (continued)

STRUCTURE			CONSISTENCE			RUP RES (a) / PENT RES (b)	MOTTLES						SURFACE FEATURES								BOUNDARY	
GRD	SZ	SHP	a)DRY b)MOIST c)OTHER	a)ST b)PL	CEM		AB	PB	CON	HUE	VAL	CHR	KND	AB	CNT	DST	LOC	HUE	VAL	CHR		
			a b c	a b		a b																1
			a b c	a b		a b																2
			a b c	a b		a b																3
			a b c	a b		a b																4
			a b c	a b		a b																5
			a b c	a b		a b																6
			a b c	a b		a b																7
			a b c	a b		a b																8
			a b c	a b		a b																9
			a b c	a b		a b																10

FREE FORM NOTES

Soil description form (continued).

FIGURE 5-2 (continued)

EFFERVESCENCE			FIELD MEASURED PROPERTIES		FIELD MEASURED PROPERTIES		WETNESS	HYDO CONDO	ROOTS			PORES				CONCENTRATIONS				ROCK FRAGMENTS				ROCK FRAGMENTS			
CL	AG	EX	KND	AMOUNT	KND	AMOUNT			QT	SZ	LOC	SHP	QT	SZ	CN	KND	QT	SHP	SZ	KND	%	RND	SZ	KND	%	RND	SZ

FREE FORM NOTES

Soil description form (continued).

FIGURE 5-3

Soil type		File No.
Area	Date	Stop No.
Classification		
Location		
N. veg. (or crop)		Climate
Parent Material		
Physiography		
Relief	Drainage	Salt or alkali
Elevation	Gr. water	Stoniness
Slope	Moisture	
Aspect	Root distrib.	% Clay *
Erosion	% Coarse fragments *	% Coarser than V.F.S. *
Permeability		
Additional Notes		

* Control section average

Horizon	Depth	Color		Texture	Structure	Consistence			Reac-tion	Bound-ary				
		Dry	Moist			Dry	Moist	Wet						

Soil description form.

The most serious error in using standard symbols is using a symbol when it is not fully appropriate. Additional notes are needed to supplement symbols that do not convey the facts completely and accurately. Another error is the introduction of individual variations in use of the standard symbols. This complicates use of descriptions by others and can defeat the purpose of standard terminology. Standard notations are used exactly as defined.

Field descriptions in which abbreviations and symbols are used can be converted to narrative form at field headquarters. If recording and transcribing facilities are available, the narrative can be dictated from the field notes and typed in block form. After narrative descriptions have been transcribed by a typist or keyed into a computer and printed, the soil scientist should check the accuracy of the descriptions.

Block Descriptions of Pedons

Comparisons among soils and within a pedon are most easily made from columnar descriptions that use standard symbols and abbreviations. The descriptions usually give dominant color, texture, mottling, structure, consistence, roots, pores, additional features, reaction, and horizon boundary. Conventions for describing each of these are given in chapter 3.

Columns of symbols and abbreviations are used mainly by soil scientist or researchers, but they can be understood by others who are familiar with narrative descriptions of typical pedons, pedons sampled for special studies, and pedons that help in defining taxa. Abbreviations and symbols used in descriptions will need to be converted to words. A standard format for narrative soil descriptions is the "block description" (see typical pedon of Sharpsburg series in Appendix II).

Maps and References

The selection of a mapping base for a soil survey is discussed in chapter 4. Some reference maps that also are useful in conducting a soil survey are mentioned. Much geographic information pertinent to soil survey work is available on maps published by various public and private organizations. Maps dealing with climate have been prepared in the past by the Weather Bureau and, more recently, by its successor in the National Oceanic and Atmospheric Administration. Maps showing surface geology and bedrock geology are prepared by U.S. Geological Survey, State geological surveys, and various other State agencies, including some universities. Topographic maps are available for most areas; some have overprints showing patterns of vegetation. For some

areas, maps showing vegetation, land use, and long-range zoning or land-use planning are available.

Many reference maps are large and should be filed without folding. A plan file or map file large enough to accommodate them can be purchased or improvised. A simple file made from hardboard or plywood is adequate. The file should have a systematic index so that maps can be found readily.

The soil survey field sheets can normally be stored in a letter file. Atlas-size sheets need legal-size or larger files. Individual aerial photographs can be filed by flights which can be separated by file indexes. The index map to field sheets is a part of this file. Some care is required in filing and handling completed field sheets to avoid cracking the photographic emulsion or abrading the inked boundaries and symbols. The file and the completed field sheets should be protected from fire, loss, and theft. Field sheets can be photographed as soon as they are completed. The prints or negatives should be stored where a fire cannot destroy both the reproduction and the originals.

During a soil survey, a substantial number of references are accumulated. One of the first activities of the survey party is assembling a list of available reference material about the survey area and its soils. This list is updated during the survey. Some of the documents are kept in the soil survey office; others are available only in libraries. Documents that are generated during a survey also become references. By the time of final preparation of the manuscript for publication, a substantial amount of reference material will have been accumulated and should be readily accessible.

Literature data bases, covering virtually every field of science and technology, are available through the National Agriculture Library and commercial information systems. Bibliographies can be prepared from the data bases for specific research problems, or general bibliographies can be prepared for several subjects in a selected geographic area. A data base is searched through an interactive computer terminal connected by telephone to the information system computer. Using selected search terms and codes, the operator examines the entire data base, selects data sets and narrows them from general to specific. The retrieved citations can be printed on-line, which is faster for short lists, or off-line, which is more economical for long lists.

Photographs

Photographs can illustrate important things about a soil in soil survey reports, scientific journals, textbooks, and periodicals. Color transparencies are ideal for slide presentations and color publications. Good photographs provide records and reference sources of basic soils information. It is necessary to plan early in the soil survey to begin taking photographs.

Photographs that include a scale are useful in estimating volume, area, or size distribution. The comparison of coarse fragments in a soil against photographs of known quantities of coarse fragments improves the reliability of estimates. Similar photographic standards can be used to estimate volume or size of nodules and concretions, mottles, roots, pores, and rock fragments. In like manner, photographic standards can be used in estimating area or the special arrangement of surface features and land use.

Equipment for field use.—Cameras suitable for soil survey documentation include the 35-mm single-lens reflex, the 2 ¼ twin-lens reflex, and the 4x5 "press" camera. Self-developing cameras have proved very useful for recording and documenting information for immediate and future reference.

A tripod is necessary, especially at shutter speeds below $^1/_{50}$ second. Use of a tripod reduces camera movement and enables the photographer to concentrate on composition and focus. A flash is necessary in some poorly lighted situations or to eliminate shadows.

Certain other items of field equipment are necessary for good pictures of soil profiles. A scale to indicate depth or thickness is important. A scale that does not contrast greatly with the soil, such as an unvarnished and unpainted wood rule or a brown or khaki cloth tape, 5 cm by 1.5 m, can be used effectively. Large black or yellow figures at 50-cm intervals, large ticks at 10-cm intervals, and small ticks at 5-cm intervals complete the scale.

A small spatula, kitchen fork, or narrow-bladed knife is useful for dressing the soil profile. Paint brushes of various widths and a tire pump aid in cleaning dust from peds. A sprayer can be used to moisten the profile when necessary.

Photographing soil profiles.—Careful planning is essential for obtaining high-quality photographs of soil profiles. A representative site is selected on a road cut or borrow-pit face or in an area where a pit can be dug large enough for adequate lighting of all horizons and for the camera to be 1½ to 2½ m from the profile. The pit or cut face should be oriented so that when the picture is taken the maximum amount of light will strike the prepared face at the proper angle.

The profile will need to be properly prepared to bring out significant contrast in structure and color between the soil horizons. Beginning at the top, fragments of the soil can be broken off with a spatula, kitchen fork, or small knife to eliminate digging marks. Dust and small fragments can be brushed or blown away. Moistening the whole profile or part of it with a hand sprayer is helpful in obtaining uniform moisture content and contrast.

Every profile should be photographed three or four times with different aperture settings, angles of light, or exposure times. Notes should be made immediately after each photograph is taken to record location and date, complete description of the subject, time of day, amount and angle of light, camera setting, method of preparing the profile, and other facts that will not show in the photograph. Besides adding to the way the photograph can be used, good notes provide information for improving technique. If possible take a landscape photograph to accompany the soil profile photograph.

Photographing landscapes.—Landscape photographs illustrate important relationships between soils and geomorphology, vegetation, and management. They should be clear, be in sharp focus, and have good contrast. Needless to say, photographs that are representative of the area being mapped are the most useful.

The most important thing in landscape photography is lighting. The best pictures are made at a time of day and during the time of year when the sun lights the scene from the side. The shadows created by this lighting separate parts of the landscape and give the picture depth. Photographs taken at midday or with direct front lighting lack tonal gradation and, therefore, appear flat. Photographs taken on overcast days are unsatisfactory for the same reason. A small enough aperture should be used to gain maximum depth of focus.

A good photograph has one primary point of interest. Objects that clutter the photograph—utility poles, poorly maintained roads and fences, signs, vehicles, and personal items placed to show scale—detract from the main point. The point of interest should not be in the center of the photograph. The "rule of thirds" for composition is used by looking at the scene through the viewfinder and visualizing the image area divided into thirds both horizontally and vertically. The center of interest is placed at one of the four points where these lines intersect. The image should contain no more than one-third sky, and the camera must be kept level with the horizon.

Photographs should be taken from a variety of angles—from a kneeling position, on a ladder, on top of a car or low building.

Close-up photography.—Many soil features such as peds, pores,

roots, rock fragments, krotovinas, mottles, concretions, and organisms can be photographed at close range.

The minimum focusing distance for most cameras used in the field is such that small features can be photographed. Short distances require a much smaller aperture setting and, consequently, a slower shutter speed to ensure adequate depth of focus.

Macrolenses are available for 35-mm cameras. These lenses permit focusing as close as about 4 inches. They usually have a focal length of 50 to 55 mm and can be used for general photography as well. Close-up attachments for conventional lenses are available.

As with landscape photography, the lighting angle is important in close work. Direct front lighting tends to blend texture, separation, and contrast in the photograph.

Photographing clay films and other minute soil features requires special equipment and techniques of photomicrography that are outside the range of this manual.

Filing and care of negatives and prints.—A file system similar to that used for field notes is helpful. Most photographs taken in support of a soil survey can be related to a taxonomic unit or map unit and filed by series. A subject card file with cross-references permits the greatest use of photographs with the least effort. Photographic files should be organized in the same way as files of notes. Negatives can be filed with each print in individual envelopes for protection. Card files of an appropriate size with dividers are satisfactory for storage.

Color 35-mm transparencies can be filed in clear vinyl pages, 22 cm by 28 cm, with pockets for individual slides. These pages are kept in 3-ring binders appropriately divided. Pages can be held to a light source for a quick search of the file. All photographs and negatives should be kept in a cool area that is isolated from chemicals and cleaning materials.

Automated Data Processing (ADP)

A large amount of many kinds of data are collected on a soil survey. How to handle accumulated data to make full use of them always is a problem. A powerful tool for dealing with this problem is ADP using computers and word processing data base and spread sheet programs. ADP makes possible timely summaries, comparisons, and analyses that otherwise would be impractical or impossible. It enables frequent and inexpensive updating of long lists, such as lists of soil series for States, regions, or the entire Nation, in any order or sequence. Such summaries can provide information to guide important policy decisions. ADP can quickly perform routine, time-consuming

computations. It allows for easy editing of descriptive materials, manuscripts, and so forth.

ADP is now widely used in soil survey and its use is expected to increase greatly. Soil scientists need to know the fundamentals of ADP just as they need to know the fundamentals of chemistry, botany, geology, mathematics, economics, and other subjects that support the work of soil survey. Literature on the fundamentals of ADP is readily available. Automated data processing can be used for many soil survey tasks, but this is not to say that it should be used for all of them. Before any decision is made to use ADP, an objective study—systems analysis—is needed to determine what combination of equipment, personnel, and other factors will be the most useful and economical. Any new system to be used must take into account the compatibility with systems used by cooperating agencies to handle soil survey data and related physical and environmental data. Many combinations of computers, storage media, input-output devices, and communications facilities are possible.

Even after an ADP system has been designed and implemented, study continues. ADP technology is changing rapidly, and new equipment and new procedures are appearing constantly. As experience is gained, an existing system may need to be improved or replaced.

Automated data processing can manipulate data in many ways. Because most of the data are likely to be needed in different combinations, the basic use is likely to be data storage and retrieval. Such a use requires that precisely and consistently defined records be entered into some medium readable by computers and arranged in cataloged files. These files of soil records are a soil survey data bank. Data banks can be kept at more than one location, depending on needs and facilities. Also, soils data can be entered into banks at more than one location. A uniform coding system is essential so that the data in the banks will have a consistent format. A uniform coding system permits direct transfer and sharing of data and the computer programs used to manipulate the data.

After the soils information has been systematically entered into the data bank and the necessary equipment and operating instructions have been organized, the data are available for many kinds or operations. Computer programs (software) must be developed if they do not already exist. Software development is usually the most expensive and time-consuming aspect of data processing. A good data management system can reduce the amount of software needed. Some examples of the important applications for soil survey are:

1. Questions can be answered: What soils have certain sets of properties? What soils are mapped in specified localities? What soils will produce corn yields of more than 100 bushels per acre under a particular management system?

2. Statistical studies, particularly multiple correlations, can be made for many purposes. These include: testing the numerical limits of values in *Soil Taxonomy*, determining what soil properties observable in the field correlate well with laboratory results, and determining what observable soil properties reliably indicate soil behavior.

3. Summaries can be prepared by ADP—summaries of interpretations by soil families, or phase of soil families, subgroups, and so on; summaries of the acreage of kinds of soil in States, drainage basins, or other geographic areas; and summaries of the number and area of soils having selected features, such as a fragipan.

4. Tabular material can be arranged and printed out for soil survey manuscripts and other reports. Text that is repeated in published surveys of a given State or region can be stored in finished form.

5. Lists, such as the classification of soil series, can be stored and easily updated.

6. Interpretative maps can be printed on demand. This is likely to become an increasingly valuable application for soil management and land-use planning.

Additional examples could be cited. As experience with ADP is gained, many additional applications will become apparent. Users of ADP outputs must be aware of the importance of reliable and accurate original information. High-quality data must be entered in the first place; ADP cannot improve the quality of the data.

CHAPTER 6 Interpretations

Approaches to Generalizing Relative Soil Behavior

This chapter explains the concepts and principles used in the interpretation of data to evaluate or predict suitabilities, limitations, or potentials of soils for a variety of uses (see appendices for examples). Interpretation is a process that continues as long as a soil survey is in use.

Soil survey information answers a wide range of soil-related questions. There is also a great range in complexity as the soils information is sometimes used alone and sometimes as one layer of information in integrated systems that also consider other natural resources, demographics, climate, and ecological and environmental factors in decision-making. Soil survey data make up a growing number of geographic information systems and models that deal with regional planning, erosion prediction, crop yields, and even modeling of global change.

Historically, soil survey interpretations have been concerned primarily with soil interpretative predictions for the public that are specific to a land use. This contrasts with genetic or taxonomic evaluation of soils by scientists. The level of data collection needed to execute the current interpretations program of the National Cooperative Soil Survey is in relevant parts of the *National Soils Handbook* (Soil Survey Staff).

Generally, preparation of interpretations involves the following steps: (1) assembling information about the soils and the landscapes in which they occur, (2) modeling other necessary soil characteristics from the soil data, (3) deriving inferences, rules, and guides for predicting soil behavior under specific land uses, and (4) integrating these predictions into generalizations for the map unit.

Soil interpretations provide numerical and descriptive information pertaining to a wide range of soil interpretative predictions. This information can be expressed in classes and units of measure of other disciplines. For example, presentation of particle size data includes both the soil separates of sand, silt, and clay, and the USDA Texture or UNIFIED classes. Generally, evaluations are made for specified uses. Soil properties that limit the land use or establish the severity of the limitation are usually indicated. Relative suitability of the soil and characteristics that

determine the suitability may be given. In addition, soil interpretations may provide displays of soil interpretative evaluations for different uses on an areal basis at scales that pertain to a specific application.

Alternative management decisions can be derived from soil behavior information. For a particular land use, this requires information on soil response to management alternatives, identification of the kinds of management needed, and information about the benefit-to-cost relationship for the management selected.

A number of considerations should be kept in mind in the use of soil survey interpretations:

- An interpretation, such as suitability for septic tank filter fields, has a specific purpose and rarely is adaptable without modification to other purposes.

- Application of interpretations for a specific area of land has an inherent limitation related to the variability in the composition of delineations within a map unit. The limitation is related to how soil surveys are made and to the size of the area of interest relative to that of map unit delineations. These concerns are particularly significant for areas of land for which large capital expenditures are contemplated, as for example, house sites. These areas are usually small relative to the size of map unit delineations and may fall within a dissimilar inclusion of soils that have interpretations completely different from those of the major components of the unit. These concerns are increased for multitaxa units.

- The inherent variability of soils in nature defines the restraints in soil interpretations and the precision of soil behavior predictions for specific areas. Interpretations based on soil surveys are rarely suitable for such onsite evaluations as home sites without further evaluations at the specific site. Soil interpretations do provide information on the likelihood that an area is suitable for a particular land use; and, thereby, they are valuable for screening areas for a planned use. This likelihood may be expressed as a suitability or a limitation.

- Specific soil behavior predictions are commonly presented in terms of limitations imposed by one or a few soil properties. The limitations posed by a particular soil property must be considered along with those of other soil properties to determine the

property that poses the most serious limitation. Shrink-swell, for example, may be the only limiting soil property for building houses with basements on some soils. Other soils, however, which have high shrink-swell, may also have bedrock at shallow depths. The shallow depth to bedrock may represent a greater limitation than does shrink-swell. Relatedly, some soils have low shrink-swell which is favorable to house sites, but they have limitations because of wetness, flooding, slope, or some other reason.

- Certain considerations that determine the economic value of land are not a part of soil interpretations but are an integral part of developing soil potentials for a given land use. For example, the location of an area of land in relation to roads, markets, and other services is considered by local groups when developing soil potential ratings based on costs to maintain the soil resource versus benefit derived.

- Some interpretations are more sensitive to changes in technology and land uses than others. Crop yields have generally increased over time and new practices may reduce limitations for nonagricultural uses. An example of the latter is the change to reinforced concrete slab-on-ground house construction, which has markedly reduced the limitation of shrink-swell for small building construction. Additionally, new uses of land will require new prediction models for soil interpretations.

- Finally, interpretations based on properties of the soil in place are only applicable if characteristics of the area of land are similar to what they were when the soil mapping was accomplished. Physical movement, compaction or bulking of soil material, or changes in the patterns of water states by irrigation, drainage, or alteration of runoff by construction may require that new interpretations be made.

Interpretative Systematics

Interpretations involve predictions about soil behavior or soil attributes. Interpretations are commonly made separately for all components in the map unit name. A summary rating for the whole unit may also be given.

The generalizations are based largely on a known or obtainable set of soil properties that are maintained or predicted for each kind of soil. These known or obtainable sets of properties or characteristics of soils

are used to predict other attributes of soil, such as shrink-swell potential or potential for frost heave. In addition, documented experience with soils having certain sets of properties are used to generalize or predict. These generalizations are commonly formalized in interpretative criteria tables for computer-generated ratings.

The interpretative criteria may range from a narrow set of inferences for specific uses or applications (for example, limitation of the soil for trench-type sanitary landfill) to a highly integrative set of inferences about complex practices that are based on a large number of considerations, only some of which are interpretative soil properties (such as the Land Capability Classification System). The criteria may be based on knowledge of how soils perform under different uses or on research inferences.

Highly integrative generalizations are made for what are called *management groups*. Groupings of soils may be made for the purposes of various national inventories. These groupings may be highly integrative (as for example, prime farmland) or be based on a few, quite specific criteria (such as highly erodible lands). Because such interpretative groups as prime farmland, highly erodible land, and hydric soils are referenced in legislation, their care has become important in national environmental objectives.

The soil properties selected and the criteria employed for making the interpretative generalizations are applicable to a very wide range of soils on a national basis. The system is not sensitive to locally important differences among soils with the same interpretative placement. For local decisions, relative rankings within the same interpretative placement may be extremely important because frequently the question is how to make the best decision within a locale. Interpretative criteria may have to be adjusted to reflect regional or local peculiarities. *Soil potentials* attempt to rationalize between the constraints of a national interpretative system and the advantages of making decisions locally on a relative basis.

Management Groups

Management groups identify soils that require similar kinds of practices to achieve acceptable performance for a soil use. In practice, management groups are limited to uses that involve the growth of plants; in theory, management groups could pertain to nonagricultural uses. All of the soils in a management group are not expected to have identical management needs; although, the needs defined for each management group must apply to all of the included soils. The broader the groups, generally the less specific are the descriptions of the management needs. The number of classes for a management group depends on the range of

soil properties, the intensity of use, the purpose of the grouping, the audience for which it is intended, and the amount of pertinent information available. The number of classes must balance between the need for homogeneity within a class and the complexity that results from increasing the number of classes. The advantages of management groups can be destroyed by making the classes either so broad that the soils within a group differ greatly or so narrow that the number of classes is large and the differences among classes too small.

The most generally applied soil management group is the land capability classification system for farming. Other management groups are the woodland suitability groups and range sites. Recently, management groups have been defined for purposes of a national soil inventory. Prime farmland, for example, is a kind of management group. More recent groups include the Fertility Classification System (Sanchez et al., 1982) and methods to group soils based on productivity indices and resilience of soils to certain uses.

National Specific-Use Placements

This section considers nationally developed evaluations for closely defined soil uses. Most of the interpretations for narrowly defined objectives can be stated as either limitations or suitabilities. Some users may prefer an expression that employs both approaches, such as stating the suitability and also listing the limiting properties according to severity or difficulty to overcome.

Historically, limitations have been the favored form for prediction about the interpretations of a soil for a particular use. Actually, the expression of interpretations may take any form that suits the needs of the user. Some users prefer a positive statement with a listing of limiting properties. The septic tank absorption system suitability rating is an example of a prediction based on limitations.

Interpretations that involve the soil as a source of something or as a material (for example, top soil) have been framed in terms of relative suitabilities rather than limitations. In addition to limitations and suitabilities, interpretative generalizations employ the probability of occurrence (such as source of sand and gravel) and a listing of the restrictive interpretative soil properties without a class placement (such as aspects of water management).

Limitation ratings.—Soils may be rated according to limitations for soil uses. Limitation ratings are usually based on hazards, risks, or obstructions presented by properties or characteristics of undisturbed soil. Limitation ratings use terms of severity such as slight, moderate, or severe.

Slight. Presents, at most, minor problems for the specified use. The soil gives satisfactory performance with little or no modification. Modifications or operations dictated by the use are simple and relatively inexpensive. With normal maintenance, performance should be satisfactory for a period of time generally considered acceptable for the use.

Moderate. Does not require exceptional risk or cost for the specified use, but the soil does have certain undesirable properties or features. Some modification of the soil itself, special designs, or maintenance are required for satisfactory performance over an acceptable period of time. The needed measures usually increase the cost of establishing or maintaining the use, but the added cost is generally not prohibitive.

Severe. Requires unacceptable risk to use the soil if not appreciably modified. Special design, a significant increase in construction cost, or an appreciably higher maintenance cost is required for satisfactory performance over an acceptable period of time. A limitation that requires removal and replacement of the soil would be rated severe. The rating does not imply that the soil cannot be adapted to a particular use, but rather that the cost of overcoming the limitation would be high.

Some soils have such extreme limitations that they should be avoided for certain uses unless no reasonable alternatives are available. Such soils have one or more features that are so unfavorable for the use that the limitation is extremely difficult and expensive to overcome. For example, shallow bedrock or inundation for a long duration are extreme limitations for onsite sewage disposal and for underground utilities. The rating of *very severe* is sometimes used for such extreme cases.

Suitability ratings.—Soils may be rated according to the degree of suitability for specific uses. Suitability ratings are based on the characteristics of the soils that influence the ease of using or adapting a soil for a specific use. A three class suitability system is commonly used.

Good. Includes soils that have properties favorable for the specified use. Satisfactory performance and low maintenance cost can be expected.

Fair. Includes soils that have one or more properties that make the soil less suitable than those rated good.

Poor. Includes soils that have one or more properties that are unfavorable for the specified use. Overcoming the unfavorable properties requires special design, extra maintenance or cost, or field alteration.

A fourth class, *unsuited*, is sometimes used for soil or soil material that is unacceptable for the specific use unless extreme measures are employed to alter the undesirable characteristics.

Suitability ratings may also be supplemented with the restrictive features that affect the performance of a soil for a specific use. These restrictive features may be a list of soil properties that are important for a specific use and may be listed with each class for which they apply. An example is, *fair*—watertable at depths of 25 to 50 cm, *poor*—bedrock at depths of less than 50 cm. Listing suitabilities with restrictive features in this manner gives the user more complete information by identifying other properties or features that may need treatment for the given use.

Other generalizations.--Evaluation of limitation or suitability is not feasible for some uses. For sand and gravel as construction material, a kind of soil may be rated only to show the probability of finding the material in suitable quantity. For some uses, the restrictive features may be given without a rating; for example, the features affecting use of the soil for irrigation or drainage of cropland. Commonly, the location is fixed for such soil uses and alternative sites are less of a consideration. The question then becomes what are the problems rather than whether to use the soil for the desired purpose. Merely noting features can be helpful to users, especially if important interactions are recorded.

Local Relative Placements

If interpretations are locally made, it becomes feasible to rank soils on a strictly relative basis and to introduce local knowledge about soil behavior that may have been excluded from more general national ratings. The term *soil potential* has been used to describe locally controlled numerical ratings that give the relative ranking of soils for a given use. This is in contrast to the national specific-use interpretative system which emphasizes criteria that apply nationwide and thus are more general than rankings based on local data that include costs to overcome limitations and costs to maintain a system.

The process of determining a soil potential requires an evaluation of the capacity of the soil to produce a crop or support a given structure or activity at a cost expressed in economic, social, and environmental units. Determination of potentials usually cannot be accomplished by soil scientists working alone. In particular, identification of corrective measures requires other disciplines.

Soil potentials for a soil survey area are of greatest value in local planning of specific tracts of land. If comparative ratings of every soil in a specific tract for a particular use are available, then a rational decision can be made whether to proceed, to change the plans, or to find another

area that has soils with higher potential. The best soils in the specific tract for the particular use may be among those with low potential in the soil survey area overall, although this fact has no bearing on the relative evaluation for the specific tract.

The extent to which a given property is limiting and, in many cases, the practices that can be used to overcome the limitation are influenced by other properties of the soil. An example is the low strength of some soils in *coarse-silty* families. Such soils may not be limiting for dwelling foundations if the shallowest depth of free water exceeds 2 m. If, however, the shallowest depth of free water is within 25 to 50 cm of the base of the foundation, then these soils may be decidedly limiting for foundations. The process of determining soil potentials, which involves the interaction of knowledgeable local people, makes it possible to use more sophisticated criteria than is feasible for the national specific-use program.

Soil potentials are presented either as a set of qualitative, relative classes or in a numerical scale. The first step is to identify for a particular use the soil properties of significance. These properties may be the same as the basic soil interpretative attributes but are not limited to these properties. Critical values for each property are defined and may include properties that are not limiting. For example, the occurrence of free water below 60 cm may not interfere with the production of soybeans; but the critical depth may be 120 cm for the production of alfalfa. Thus, soil potentials are crop and property specific.

The second step in rating soil potential is to identify the corrective measures. Alternatives that appear to be applicable for each soil use should be listed. The most common sources of information are examples where the practices have been successfully used. Soil research and field trials may identify new practices. A single practice may not be fully effective unless it is used in combination with other practices. This may require broadening the definition of a single practice to include interrelated practices. Alternative practices can commonly be substituted. For example, dwellings can be built without basements on integral slab foundations and avoid the necessity of reinforced basement walls.

The third step in rating soil potential is to determine the cost or difficulty of overcoming soil limitations. Relative rather than absolute costs of corrective measurements are generally desirable. If the cost of overcoming the limitation is judged to be prohibitive, the soil is rated to have low potential for that use. Information on cost provides a guide to landowners and local planners.

The fourth step is to identify the limitation that would exist after the corrective measures have been installed. Certain practices are fully successful in overcoming limitations on some soils. Performance is as good

as that of soils that do not have the limitations or even better. For other soils and uses, however, no corrective measures are available at an acceptable cost. For many situations, practices may substantially lessen the effects of soil properties, but problems still remain.

To express soil potentials numerically, values are assigned to those soil properties and site conditions that influence performance. Some approaches assign penalty points to limiting soil properties or site conditions, and others assign points based on favorable properties or conditions.

An illustrative formula for the Soil Potential Index (SPI) is:

$$SPI = P - CM - CL$$

P is the standard of performance or yield as locally defined. An index value of 100 for P is commonly used, but it may be any value; for example, the potential yield in kilograms per hectare may be employed. *CM* is an index of cost of the needed corrective measures. Finally, *CL* is an index of the extent to which the feasible corrective measures are not fully successful. It reflects costs for annual or periodic maintenance, for inconvenience or aggravation, or for substandard yield.

Alternatively, qualitative ratings of soil potential may be employed. An example of a three class set follows:

High potential. The soil meets or exceeds the requirements stipulated in one or more of the following statements:

(1) The soil has few limitations, or practices for overcoming the limitations are available at a reasonable cost.

(2) Crop production is profitable and at least average for the area.

(3) For a particular use, performance of the soil is satisfactory or as good as, or better than, local standards.

(4) Environmental quality, both on and off the site, is maintained at a level that is better than the average for the area.

(5) After corrective measures have been installed, any continuing soil limitations do not appreciably reduce production, performance, or environmental values.

Medium potential. The soil has a combination of properties intermediate between those qualifying for high potential and those qualifying

for low potential. Production is somewhat below local standards, cost of corrective measures is high, or continuing limitations after measures have been installed detract from environmental quality or economic return.

Low potential. The soil has a combination of properties, including one or more of the following situations:

(1) Serious soil or site limitations exist and measures for overcoming them are not available or are considered locally to be too expensive.

(2) Crop production is substantially below the local average and is economically marginal or submarginal.

(3) Performance of the soil is below local standards or below the normal expectations of the land user, even under the best available management.

(4) Environmental quality, both on and off the site, is considerably degraded by the use.

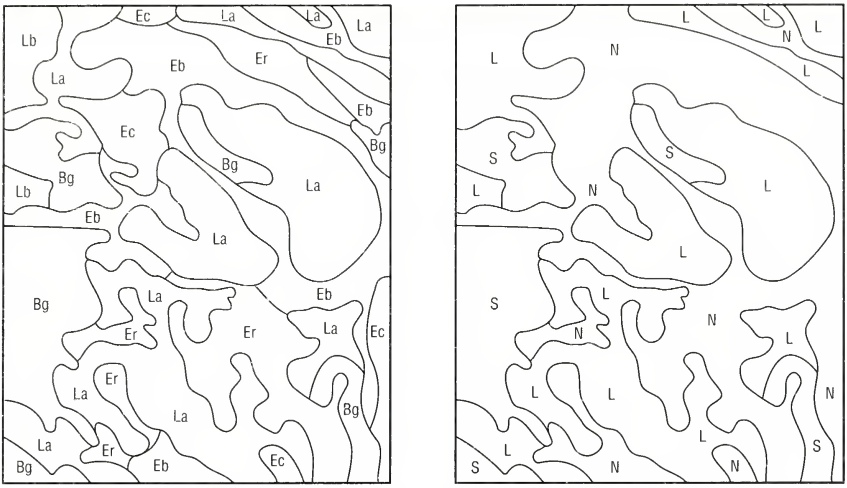
(5) Serious soil limitations continue to affect the use even after corrective measures have been installed.

A five-class system may be needed. *Very high* potential distinguishes soils that have few or no limitations affecting the land use. Only standard practices, systems, or designs are needed on these soils; no special practices involving additional cost are needed. *Very low* potential applies to soils so severely limited that they cannot be made to even marginally perform for the use.

Interpretive Soil Properties

Soil survey interpretations are provided for specific soil uses. Interpretations for each soil use are based on a set of interpretative soil properties. These properties include site generalities such as slope gradient, measurements on individual horizons (e.g., particle size distribution), temporal repetitive characteristics that pertain to the soil as a whole (e.g., depth to free water), and potential for diastrophic events (e.g., downslope movement). Most of the interpretative soil properties are included in the description text and are on the tables associated with a particular map unit (fig. 6-1).

FIGURE 6-1



Section of a detailed soil map on the left and its interpretations on the right. The map units have been rated slight (L), moderate (N), or severe (S) for a specific use.

Abbreviated descriptions follow for the more commonly used interpretative soil properties. Formal classes have been assigned to several of the interpretative soil properties. These classes generally are not given unless they are used in field morphological descriptions. All of the classes are in the *National Soils Handbook* of the Soil Conservation Service. Local conditions may dictate other interpretative soil properties or a greater emphasis on a subdivision of some of the interpretative properties here listed.

Assignment Guidelines

In principle, the system permits the assignment of interpretative soil properties and related interpretations by map unit based on the named components, generally phases of soil series. Properties of the minor components of a map unit may be included if adequate sampling techniques are used to characterize the map units of a survey area.

Commonly, representative values are specified by layers or horizons. These layers normally reflect the mode for depths and sequences of horizons for the soil series. Only major horizons are delimited and are generally related to surface layer, subsoil, and underlying material.

Ranges are commonly attached to numerical quantities. The ranges are designated to encompass both the actual variation to be expected within the modal concept of the named soil and the expected analytical variation.

FIGURE 6-2

Soils subject to flooding.

Setting

Annual air temperature.—This is the mean air temperature for the calender year.

Elevation.—This is the range in height above sea level.

Frost-free period.—This is the average length of the longest period that is free of killing frost.

Precipitation.—This is the mean annual moisture received, including rainfall and solid forms of water.

Slope.—This is the range in slope gradient in percent (ch. 3).

Field Water Characterization

Available water capacity.—This is the volume of water that should be available to plants if the soil, inclusive of rock fragments, were at field capacity. Volumes are expressed both as a volume fraction and as a thickness of water. The standard of reference is the *water retention difference* (under 4C in Soil Survey Laboratory Staff, 1992). Reductions are made in the water retention difference for incomplete root ramification that is associated with certain taxonomic horizons and features such as fragipans, and for chemical properties that are indicative of root restriction such as low available calcium and high extractable aluminum. Corrections for the osmotic effect of high salt concentrations also may be made. The amount of available water to the expected maximum depth of root exploration, com-

monly either 1 or 1 $^1/_2$ m, or a physical or chemical root limitation, whichever is shallower, has been formulated into a set of classes. For the class sets, the depth of rooting that is assumed and the class limits that are stipulated differ among the taxonomic moisture regimes.

Drainage class.—This class (ch. 3) places major emphasis on the relative wetness of the soil under natural conditions as it pertains to wetness due to a water table.

Flooding.—This refers to inundation by flowing water. Frequency and duration classes are employed. These are described in chapter 3 (fig. 6-2).

Free water occurrence.—This includes the depth to, kind, and months of the year that a zone of free water is present within the soil (ch. 3).

Hydrologic soil groups.—This is a set of classes that pertain to the relative infiltration rate of soil under conditions of maximum yearly wetness. It is assumed that the ground surface is bare and ice does not impede infiltration and transmission of water downward (ch. 3).

Ponding.—This refers to inundation by stagnant water. The duration and month(s) of the year that ponded water occur are recorded (ch.3).

Particle Size Distribution

USDA particle size classes (based on <2mm fraction).—This is the relative proportion by weight of the particle separate classes <2 mm in diameter (textural classes) as modified by adjectival classes based on the proportion, size, and shape of rock fragments and by the proportion of organic matter if high. The classes are defined in chapter 3. Measurement is described under 1A2, 3A, and 3B (Soil Survey Laboratory Staff, 1992).

Fraction >250 mm (based on whole soil).—This quantity is expressed as a weight percent and is inclusive of unattached pieces of rock up to an unspecified upper limit, but it does not exceed the size of the pedon. The rocks more than 250 mm do not affect the Unified or AASHTO classifications, but they may have a large influence on suitability for certain soil uses (ch. 3).

Fraction 75 - 250 mm (based on whole soil).—This quantity is expressed as a weight percent of the whole soil, inclusive to an undefined upper limit which is less than the size of the pedon. Consult chapter 3 and methods 1A2 and 3B (Soil Survey Laboratory Staff, 1992). The quantity does not affect the Unified and AASHTO placements. It may, however, have a large influence on suitability for certain uses.

Percent passing sieve numbers 4, 10, 40, and 200 (based on <75mm fraction).—These quantities are the weight percent passing sieves with openings of 4.8 mm, 2.0 mm, 0.43 mm, and 0.075 mm in diameter, respectively. The quantities are expressed as a percentage of the less than 75 mm material. The percent passing the number 4 and 10 sieves may be estimated in the field (ch. 3), or measured in the office or labora-

tory under methods 1A2 and 3B (Soil Survey Laboratory Staff, 1992). The material passing the 40 and 200 sieves may be measured directly in the laboratory (designation D 422-063, ASTM, 1984) or estimated from the USDA particle separate measurements made as described under 3A (Soil Survey Laboratory Staff, 1992).

Clay (based on <2mm fraction).—This is the <0.002 mm material as the weight percent of the total <2 mm. The pipette method under 3A (Soil Survey Laboratory Staff, 1992) is the standard. For soils that disperse with difficulty, the clay percentage commonly is evaluated from the 1500 kPa retention under 4B (Soil Survey Laboratory Staff, 1992). Carbonate of clay size is included.

Fabric-Related Analysis

Moist bulk density.—This is the oven dry weight in megagrams divided by the volume of soil in cubic meters at or near field capacity, exclusive of the weight and the volume of fragments >2 mm. Method 4A1 in (Soil Survey Laboratory Staff, 1992), the so-called clod density method, is the common laboratory reference determination.

FIGURE 6-3

Cracks in a vertisol.

Shrink-swell potential.—These are a set of classes of reversible volume change between field capacity and oven-dryness for a composition inclusive of rock fragments. Actual shrink-swell, in contrast, is dependent on the minimum water content that occurs under field conditions. The standard laboratory method 4D (Soil Survey Staff Laboratory, 1992), involves computation of the strain from the volume decrease of bulk density clods that are oven-dried from the water content at the suction selected to estimate field capacity, (fig. 6-3).

Available water capacity.—This is the volume of water that should be available to plants if the soil, inclusive of rock fragments, were at field capacity. Values are expressed both as a volume fraction and as a thickness of water per thickness of soil. The standard of reference is the water retention difference under 4C (Soil Survey Laboratory Staff, 1992). Reductions are made in the water retention difference for incomplete root ramification associated with certain taxonomic horizons and features such as fragipans, and for chemical properties indicative of root restriction such as low available calcium, and high extractable aluminum. Corrections for the osmotic effect of high salt concentrations also may be made.

Saturated hydraulic conductivity.—This class placement pertains to the amount of water that would move downward through a unit area of saturated in-place soil in unit time under unit hydraulic gradient (ch. 3). Estimates are based on models that relate laboratory measurements on soil cores to the interpretative soil properties and morphology (O'Neil, 1952; Baumer, 1986). The quantity has been referred to as *"permeability."*

Engineering Classification

Liquid limit.—This is the water content at the change between the liquid and the plastic states. It is measured on thoroughly puddled soil material that has passed a number 40 sieve (0.43 mm) and is expressed on a dry weight basis (ASTM method D 4318-83 in ASTM, 1984).

Plasticity index.—This is the range in water content over which soil material is plastic. The value is the difference between the liquid limit and the plastic limit of thoroughly puddled soil material that has passed a number 40 sieve (0.43 mm). The *plastic limit* is the water content at the boundary between the plastic and semisolid states. The measurement of the plastic limit is described in ASTM method D 4318-83 (ASTM, 1984).

Unified classification.—This is a classification of soil material designed for general construction purposes. It is dependent on the particle size distribution of the <75 mm, the liquid limit, and the plasticity index and on whether the soil material is high in organic matter (ASTM test D 2487, in ASTM, 1984). There are three major divisions: mineral soil material having below 50 percent particle size <0.074 mm (pass 200

mesh), mineral soil material having 50 percent or more particle size <0.074 mm, and certain highly organic soil materials. The major divisions are subdivided into groups based on the liquid limit, plastic index, and the coarseness of the material that exceeds 0.074 mm (retained on 200 mesh).

AASHTO classification.—This is a classification of soil material for highway and airfield construction (Procedure M 145-73. In Am. Assoc. of State Highway and Transportation Officials, 1984). It is based on the particle size distribution of the <75 mm and on the liquid limit and the plastic index. The system separates soil materials having 35 percent or less, which is <0.074 mm, from those soil materials having over 35 percent. Each of these two divisions are subdivided into *classification groups* based on guidelines that employ particle size, liquid limit, and volume change. A *group index* may be computed based on the liquid limit and plasticity index in addition to the percent <0.074 mm. The *group index* is a numerical quantity based on a set of formulas.

Chemical Analysis

Calcium carbonate equivalent.—The methods under 6E (Soil Survey Laboratory Staff, 1992) are the standard of reference.

Cation exchange capacity.—The methods of reference are 5A3b for soil with a pH below 5.5 and method 5A8 if the pH is 5.5 or above (Soil Survey Laboratory Staff, 1992).

Gypsum.—The quantity pertains to the <20 mm. The methods of reference are under 6F (Soil Survey Laboratory Staff, 1992).

Organic matter.—The methods of reference are under 6A (Soil Survey Laboratory Staff, 1992). Measured organic carbon is multiplied by a factor of 1.72 to obtain organic matter.

Reaction (pH).—The standard is the 1:1 water pH (method 8C1f, Soil Survey Laboratory Staff, 1992). For organic soil materials the pH in 0.01M $CaCl_2$ is employed. Classes are in chapter 3.

Salinity.—A set of classes is employed for the concentration of dissolved salts in a water extract. The classes are expressed as electrical conductivity. The measurement of reference is made on water extracted from a saturated paste (method under 8A, Soil Survey Laboratory Staff, 1992). Units are decisiemens per meter (dS/m).

Sodium adsorption ratio.—This is evaluated for the water extracted from a saturated soil paste. The numerator is the concentration of water soluble sodium and the denominator is the square root of half of the sum of the concentrations of water soluble calcium and magnesium (5E, Soil Survey Laboratory Staff, 1992).

Sulfidic materials.—On exposure to air the pH of soil materials that

contain significant sulfides becomes very low. The requirements are defined in the latest edition of the *keys to soil taxonomy*. Methods for total sulfur are under 6R (Soil Survey Laboratory Staff, 1992). Direct measurement of the pH after exposure to air is also employed.

Physical Features or Processes

Depth to bedrock.—This refers to the depth to fixed rock. Hard and soft bedrock are distinguished. Hard bedrock is usually *indurated* but may be *strongly cemented*, and excavation difficulty would be *very high or higher* (ch. 3). Soft bedrock meets the consistence requirements for *paralithic* contact (Soil Survey Staff, 1975).

Depth to cemented pan.—This is the depth to a pedogenic zone that is *weakly cemented* to *indurated* (ch. 3). *Thin* and *thick* classes are distinguished. The thin class is less than 8 cm thick if continuous and less than 45 cm if discontinuous or fractured. Otherwise, the thick class applies.

Mass movement.—Three kinds of rather large scale irreversible soil movement are recognized: *downslope movement* may occur if the soil is loaded, excavated below, or is unusually wet; *ice-melt pitting* may result from melting of ground ice after vegetative cover has been removed; and differential settling may occur related to wet-dry cycles.

Total subsidence.—This is the potential decrease in surface elevation as a result of drainage of wet soils having organic layers or semifluid mineral layers. The subsidence may result from several causes: loss of water and resultant consolidation; mechanical compaction; wind erosion; burning; and of particular importance for organic soils, oxidation.

Depth to permafrost.—The critical depth is determined by the active layer. Utilities, footings, and so on are placed below the active layer. The minimum depth is affected by the depth of annual freezing. Permafrost depth may be strongly influenced by the soil cover.

Potential frost action.—This pertains to the likelihood of upward or lateral movement of soil by formation of ice lenses and the subsequent loss of soil strength upon thawing. Large scale collapse to form pits is excluded and considered under mass movement. Soil temperature, particle size, and the pattern of water states are used to make predictions.

Erosion

The K Factor.—The factor appears in the Universal Soil Loss Equation (Wischmeier and Smith, 1978) as a relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall. Measurements are made on plots of standard dimensions. Erosion is adjusted to a standard of 9 percent slope. K factors are currently measured by applying simulated rainfall on freshly tilled plots. Earlier meas-

urements integrated the erosion for the year for cultivated plots under natural rainfall. K may be computed from the composition of the soil, saturated hydraulic conductivity, and structure.

The T Factor.—This is the soil loss tolerance which can be used with the Universal Soil Loss Equation (Wischmeier and Smith, 1978). It is defined as the maximum rate of annual soil erosion that will permit crop productivity to be sustained economically and indefinitely. The T factors are integer values of from 1 through 5 tons per acre per year. The factor of 1 ton per acre per year is for shallow or otherwise fragile soils and 5 tons per acre per year is for deep soils that are least subject to damage by erosion.

Wind erodibility groups.—This is a set of classes given integer designations from 1 through 8, based on compositional properties of the surface horizon that are considered to affect susceptibility to wind erosion. Texture, presence of carbonate, and the degree of decomposition of organic soils are the major criteria. Associated with each wind erodibility group is a *wind erodibility index* in tons per acre per year. The wind erodibility index is the theoretical, long-term amount of soil lost per year through wind erosion. It is based on the assumption that the soil is bare, lacks a surface crust, occurs in an unsheltered position, and is subject to the weather at Garden City, Kansas (Woodruff and Siddoway, 1965). Tillage frequency and practices are not specified.

Corrosivity

Uncoated steel.—The rating depends on texture, drainage class, extractable acidity (methods under 6H, Soil Survey Laboratory Staff, 1992), and either resistivity of a saturated soil paste or electrical conductivity of the saturation extract (methods under 8E and 8A, respectively, Soil Survey Laboratory Staff, 1992).

Concrete.—The ratings depend on texture, occurrence of organic horizons, pH, and the amounts of magnesium and sodium sulfate or sodium chloride in the saturation extract (methods under 8A, 8C, and 6, Soil Survey Laboratory Staff, 1992).

Interpretative Applications

In this section the process of developing soil interpretations for land uses is discussed and the kinds of soil interpretations or groupings of soils are presented.

Soil interpretations may be developed at many levels of generalization or abstraction. Traditionally, interpretations have been developed for national application. These criteria, however, may be too general for

applications at the local or regional levels. The national criteria, however, may be the basis from which to narrow limits or add further criteria for the local situation.

The process of developing interpretations for a specific land use follows a scientific method as do other processes in a soil survey. The soil scientist or group preparing the criteria reviews the literature, interviews experts, makes observations of soil performance under the specific use, develops a set of criteria using the basic soil properties, tests the criteria, and finally adopts the system. The process rarely becomes static. As new technologies become available, the criteria must be reevaluated.

Soil interpretations are a paradigm of how soils respond for a specific use. They are models that use a set of rules or criteria that are based on, or fed by, the basic soil properties, modeled properties, or classes of properties. In some cases it may be necessary to model a subset or intermediate interpretation to evaluate potential frost action, corrosivity, or potential for mass movement.

The interpretations are most often developed in response to user needs, thus the development process must include input from the user and professionals from other disciplines. User feedback is crucial in the iterative process of refining a specific interpretation.

Example.—Table 6-1 contains the criteria for interpreting soils for septic tank filter fields. Table 6-2 illustrates how the criteria are applied to the map unit of Sharpsburg soils in the appendix. These tables are used to illustrate the process of developing an interpretation. (N.B.: The classes of hydraulic conductivity are those used currently in interpretations and are not coincident with the new class limits given in ch. 3.)

The soil scientist or group of individuals developing an interpretation first determine a list of soil properties that are known, or are thought to be, important for septic tank filter fields. Depth to water table, permeability, depth to bedrock, depth to cemented pan, depth to permafrost, slope, flooding, ponding, susceptibility to downslope movement, and susceptibility to pitting are considered important properties in this case. After determining the list of soil properties, the soil scientist or group of individuals develop limits for each property and each class (slight, moderate, severe). This iterative phase is often the most difficult. The initial set of criteria is tested in different areas of the country using a wide array of soil conditions. Results of the tests may require adjustments to the criteria and retesting. Once the limits are set they may be arrayed in the table according to degree of severity or importance.

Testing and reevaluation.—The interpretative paradigm is under continuous scrutiny by user feedback, ranging from local homeowners' associations and units of government to national environmental agen-

TABLE 6-1

Interpretive Soil Properties and Limitation Classes for Septic Tank Absorption Suitability.

Interpretive Soil Property	Limitation Class Slight	Moderate	Severe
Total Subsidence (cm)	—	—	> 60
Flooding	None	Rare	Common
Bedrock Depth (m)	> 1.8	1-1.8	< 1
Cemented Pan Depth (m)	> 1.8	1-1.8	< 1
Free Water Occurrence (m)	> 1.8	1-1.8	< 1
Saturated Hydraulic Conductivity (μm/s)			
Minimum 0.6 to 1.5 m a/	10-40	4-10	< 4
Maximum 0.6 to 1 m a/			> 40
Slope (Pct)	< 8	8-15	> 15
Fragments > 75 mm b/	< 25	25-50	> 50
Downslope Movement			c/
Ice Melt Pitting			c/
Permafrost			d/

a/ 0.6 to 1.5 m pertains to percolation rate; 0.6 to 1 m pertains to filtration capacity

b/ Weighted average to 1 m.

c/ Rate severe if occurs.

d/ Rate severe if occurs above a variable critical depth (see discussion of the interpretative soil property).

cies and organizations. Soil scientists continue the testing of interpretations through observations and discussions with local user groups during the soil survey process.

National Inventory Groupings

Technical soil groupings have been developed as criteria for the application of national legislation concerned with the environment and with

TABLE 6-2

Values of applicable interpretative properties for septic tank suitability for Sharpsburg silty clay loam, 5 to 9 percent slopes; Soil Survey of Lancaster County, Nebraska (Brown et al., 1980).

Property	Limitation Class			Values
	Slight	Moderate	Severe	
Flooding	X			None
Bedrock Depth	X			> 1.8 m
Free Water Occurrence	X			> 1.8 m
Saturated Hydraulic Conductivity				
Minimum 0.6 to 1.5 m			X	1-4 μm/s
Maximum 0.6 to 1 m	X			1-4 μm/s
Slope		X		5-9
Fragments > 75 mm	X			trace

agricultural commodity production. Groupings may pertain to agricultural productivity and diversity, erosion potential, surface and ground water quality, maintenance of wetlands, or other groups to meet national needs. Four national groupings are described as examples: *prime farmlands, unique farmlands, hydric soils, and highly erodible lands.* Specific criteria in the *National Soils Handbook* may be studied to demonstrate how various taxonomic and nontaxonomic map unit criteria, coupled with interpretative soil properties, have been employed to construct definitions for national inventory purposes.

Prime farmland. This is land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops. It must also be available for these uses. It has the soil quality, growing season, and moisture supply needed to produce economically sustained high yields of crops when treated and managed according to acceptable farming methods, including water management. In general, prime farmlands have an adequate and dependable water supply from precipitation or irrigation, a favorable temperature and growing season, acceptable acidity or alkalinity, acceptable salt and sodium content, and few or no rocks.

They are permeable to water and air. Prime farmlands are not excessively erodible or saturated with water for a long period of time, and they either do not flood frequently or are protected from flooding.

Unique farmland. This is land other than prime farmland that is used for the production of specific high value food and fiber crops. It has the special combination of soil quality, location, growing season, and moisture supply needed to produce economically sustained high quality and/or high yields of a specific crop when treated and managed according to acceptable farming methods. Examples of crops are tree nuts, olives, cranberries, citruses and other fruits, and vegetables.

Hydric soils. These are soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part. They make up part of the criteria for the identification of wetlands.

Highly erodible land. These lands have been defined in order to identify areas on which erosion control efforts should be concentrated. The definition is based on Erosion Indexes derived from certain variables of the Universal Soil Loss Equation (Wischmeier and Smith, 1978) and the Wind Erosion Equation (Woodruff and Siddoway, 1965). The indexes are the quotient of tons of soil loss by erosion predicted for bare ground divided by the sustainable soil loss (T factor).

Land-Use Planning

Land-use planning is the formulation of policies and programs for guiding public and private land use in areas of any size where different uses compete for land. The word "land" in this context implies attributes of place and other factors besides soil. Planners must consider place, size of area, relation to markets, social and economic development, skill of the land users, and other factors. Soil surveys can help in land-use planning by serving as an introduction to the soil resources of the area and by providing a source of information for the evaluation of the environmental and economic effects of proposed land uses. Soil surveys can be interpreted for land-use planning through groupings or ratings of soils according to their limitations, suitabilities, and potentials for specified uses.

Local planning.—Local government units such as those of cities, towns, and counties do local planning. The planning applies to com-

plexes of farms and ranches, to housing developments, shopping centers, industrial parks, and to entire communities or political units.

Local planners use interpretations of soils and other information to develop recommendations on alternatives for land use, patterns of services, and public facilities. Planners may need interpretative maps at different scales depending on the objective. Interpretations of small areas for local planning rate limitations, identify management or treatment needs, and predict performance and potential of individual kinds of soils identified on detailed soil survey maps. Interpretations of areas that include entire governmental units evaluate the soils for all competing uses within the planning area. These maps are smaller in scale, and the units are associations of soil series or of higher taxa. Local planners commonly need ratings of the whole association for alternative uses. Special maps showing the location of areas having similar potentials or limitations for certain uses may be helpful for planners. Information about the amounts and patterns of soils having different potentials within each association can be given in tables or in the text of a soil survey report.

Regional Planning.—Certain problems pertain to areas that cover several political units. For these situations, regional planning is appropriate. The principal functions of regional planning are the collection, analysis, and dissemination of planning and engineering information, preparation of long-range plans, and coordination among the agencies involved.

Most soil maps for regional planning are small scale maps generalized from detailed soil survey maps. Soil interpretations show the differences between the map units in terms of suitabilities and limitations for the principal competing uses. The distribution of map units having similar behavior for a given use are commonly shown on special maps. An accompanying text describes the units, explains the basis for the ratings, and may also describe the effect of the pattern of associated soils on the use of specific parcels. Regional planners commonly need more specific information about the suitability of small parcels than can be obtained from generalized soil maps. For example, they may find an area that is generally good for recreation, but they also need to know that a potential site for a reservoir has soils suitable for storing water before the regional plan can be completed.

Farmland

Soil surveys in agricultural areas identify the soil characteristics that determine the suitability and potential of soils for farming. Interpretations for farming involve placement of the soils in management groups (land capability system) and identification of the important

soil properties that pertain to crop production, application of conservation practices, and other aspects of agriculture. The other aspects of agriculture include yield potential, susceptibility to erosion, depth to layers that restrict roots, available water capacity, saturated hydraulic conductivity, the annual pattern of soil-water states (including soil drainage class, inundation, and free water occurrence), qualities that describe tilth, limitations to use of equipment (including slope gradient and complexity, rock fragments, outcrops of bedrock, and extremes in consistence), salinity and sodium adsorption ratio, presence of toxic substances, deficiency of plant nutrients, capacity to retain and release plant nutrients, capacity to retain soluble substances that may cause pollution of ground water, capacity to absorb or deactivate pesticides, and pH as related to plant growth and the need for liming.

The fate of added nutrients and pesticides, as related to farm management and cropping systems, is an important consideration in nonpoint water pollution. The identification of critical soil properties as related to resource management systems is crucial in the wise use of the land. The *Land Capability System* shows the suitability of soils for agricultural uses (Klingebiel and Montgomery, 1961). The system classifies soils for mechanized production of the more commonly cultivated field crops—corn, small grains, cotton, hay, potatoes, and field-grown vegetables. It does not apply directly to farming systems that produce crops, such as some fruits and nuts that require little cultivation, or to crops that are flooded, such as rice and cranberries. It also cannot be used for farming systems that depend on primitive implements and extensive hand labor.

Soil productivity is the output of a specified plant or group of plants under a defined set of management practices. It is the single most important evaluation for farming. In general, if irrigation is an optional practice, yields are given with and without irrigation. Productivity can be expressed in quantity of a product per unit land area, such as kilograms or metric tons per hectare. For pasture, productivity can be expressed as the carrying capacity of standard animal units per unit area per season or year—or as live-weight gain. Productivity may be expressed as a rating or index related to either optimum or minimum yields, or it may be indexed to a set of soil qualities (properties) that relate to potential productivity. Productivity indices have the advantage of being less vulnerable to changes in technology than are expressions of productivity based on yields.

Productivity ratings express the predicted yields of specified crops under defined management as percentages of standard yields. They are calculated as follows:

$$\text{Productivity rating} = \frac{\text{predicted yield per unit area x 100}}{\text{standard yield per unit area}}$$

Such a rating provides a scale for comparing the productivity of different kinds of soils over large areas. Ratings lend themselves to numerical treatment. Productivity ratings permit comparison of the productivity of crops having yields that differ markedly in numerical values. For example, a certain soil has a yield of corn for silage of 60,000 kg/ha and of 9,000 kg/ha for grain corn. These entities represent similar levels of production so the productivity ratings would be similar. Selection of the standard yield of a crop depends on the purpose of the rating. For national comparison, the standard yields should be for a high level of management on the best soils of the region for the crop. If potential production is of interest, yields under the best combination of practices are used.

Productivity ratings for individual crops can be combined to obtain a general rating for the soil over its area of occurrence. The individual ratings are weighted by the fraction of the area occupied by each crop, and a weighted average is calculated that characterizes the general productivity of the soil.

Productivity indices tied to soil properties are used as a relative ranking of soils. Soil properties important to favorable rooting depth and available water capacity normally are chosen. Some productivity models rely on a few critical soil properties such as pH and bulk density to rate soils (Pierce et al.; 1983, Kiniry et al., 1983). The EPIC model is a comprehensive productivity calculator that integrates many soil and climatic processes (Williams et al., 1989). Giving a relative ranking to soils, as well as calculating the impact of cropping systems on soil erosion and productivity, is worthwhile.

The soil fertility capability classification (FCC) system is a technical Soil Classification system that focuses quantitatively on the physical and chemical properties of the soil that are important to fertility management (Sanchez et al., 1982). Information required by the system is obtained from pedon descriptions and associated field data, laboratory characterization data, and *Soil Taxonomy*. The system is applicable to upland and wetland rice crops, pasture, forestry, and agroforestry needs under high- or low-input systems. The system does not rank soil, but rather it states the soil properties important to management decisions which will differ by crop type and management system. The system provides management statements for the classified soil and lists the general adaptability of various crops.

Resiliency of soils is an interpretation that relates to the ability of a soil to rebound from depletion of plant nutrients or organic matter or to rebound from the degradation of physical or chemical properties. The resiliency ratings are based on estimates of the natural fertility of the soil, available water capacity, favorable rooting depth, particle size distribution, and distribution of salts in the profile, if present. Resiliency ratings are important in evaluating alternative management systems that are based on lower chemical inputs. Traditional practices that use high inputs of chemical fertilizers and pesticides often mask properties of the soils that are important to crop production. Resiliency of soils is also important in evaluating long-term affects of management systems on soils.

Rangeland

Rangeland has a native vegetation of grasses, grasslike plants, forbs, and shrubs. In many areas, introduced forage species are also managed as rangeland. The vegetation is suitable for grazing and browsing by animals. Rangeland includes natural grasslands, savannahs, many wetlands and deserts, tundra, and certain shrub and forb communities. Soil-range site correlation within a soil survey gives the suitability of the soil to produce various kinds, proportions, and amounts of plants (fig. 6-4). This knowledge is important in developing management alternatives needed to maintain site productivity. Rangeland interpretations are given as range sites.

Range sites are ecological subdivisions into which rangeland is divided for study, evaluation, and management. A range site is, therefore, a distinctive kind of rangeland that differs from other kinds of rangeland in its ability to produce a characteristic natural plant community. It is typified by an association of plant species that differs from that of other range sites in the kind or proportion of species or in total annual production. The natural plant community, in the presence of natural disturbances—fire, insects, drought—and the absence of abnormal disturbances and physical site deterioration, is the climax plant community for the range site.

A range-site description commonly contains the following information:

1. Landscape factors that describe the geographic location, physiography, and associated stream and nonstream water features of the site;

2. Climate factors that consider the soil moisture and temperature regimes, ambient climate, and moisture and temperature distribution patterns;

FIGURE 6-4

Two range sites on different soils.

3. Soil factors that are most important in developing soil-vegetation relationships and that affect plant growth—the major soil families, geologic formation, features of the soil surface, surface horizon and texture, soil depth, major root zone thickness and its available water capacity, kind and amount of accumulations, profile rock fragments, reaction, salinity, sodicity, soil-water states, water table, and flooding;

4. Vegetation factors that describe the various kinds of tree, shrub, forb, grass, and grasslike, components of the plant community:

   The vegetative factors are the percent of cover and the composition and production of the plant community. Percent composition is expressed as a range of percent for each plant species identified by air-dry weight. Production is the total annual yield of air-dry forage, expressed as a range of values that reflect long-term weather variations. Yields are usually based on measured values;

5. Species list of wildlife that are associated with the site or are expected to use the site in the climax situation and will directly influence plant community dynamics;

6. Community dynamics that describe known or expected time relationships attributed to natural disturbances—periods between wild fires, cyclic insect infestations, or other disturbances to the composition of the plant community;

7. Site interpretations that give the potential importance of the site for each of its major uses and the feasibility of restoring depleted areas by seeding suitable species.

8. Listing of soils grouped into the site by soil survey area, map unit symbol, and soil name and phase.

Forest land

Forest land is dominated by native or introduced trees with an understory that consists of many kinds of woody plants, forbs, grasses, mosses, and lichens. Some forest communities produce, at least occasionally, enough understory vegetation suitable for forage to permit grazing.

Soil-forest site correlation within a soil survey gives the suitability of the soil to produce wood products. If forest land is important in a soil survey, the estimated productivity of the common trees is given for each individual soil. The understory vegetation is described at the expected canopy density most representative of forest stands having a normal production of wood. Determination of the soil productivity for forest products requires close collaboration between foresters and soil scientists.

Wood production or yield is commonly expressed as the *site index* or as some other measure of the volume of wood produced annually. Site index is the average height of dominant and codominant trees of a given species at a designated age. Measurements of site index are usually extended to a number of like soils where data are unavailable. The site index is correlated to each soil and may be further interpreted in terms of cubic meters per hectare.

Soils may be grouped using the *ordination system*. The symbols that make up the system indicate productivity potential and the major limitations for the use and management of individual soils or groups of like soils. The first part of the ordination symbol is the *class* designator. This is a number that denotes potential productivity in terms of the nearest whole cubic meter of the wood growth per hectare per year for the soil based on the site index of an indicator tree species. For a number of species, data are available for converting site index to average annual wood growth. The second part of the ordination symbol, or *subclass*, indicates soil or physiographic characteristics that limit management—stoniness or rockiness, wetness, or restricted rooting depth. A third

component of the ordination symbol, or *group*, is sometimes employed to distinguish groups of soils that respond similarly to management. When the group symbol is used, soils that have about the same potential productivity are capable of producing similar kinds of trees and understory vegetation and have similar management needs.

Soils may be rated for such factors as susceptibility to mechanical compaction or displacement during forestry operations, limitations that result from burning, hazards from soil-borne pests and diseases and limitations imposed by specific soil properties such as wetness. The management of trees begins with an understanding of the soil on which the trees grow or are to be grown. Soil surveys include information that can be used effectively in the management of forest land; for example,

Erosion hazard. This is the probability that erosion damage may occur as a result of site preparation and the aftermath of cutting operations, fires, and overgrazing.

Equipment limitations. These are limits on the use of equipment either seasonally or year-round due to soil characteristics such as slope, surface rock fragments, wetness, and surface soil texture.

Seedling mortality. This rating considers soil properties that contribute to the mortality of naturally occurring or planted tree seedlings such as droughtiness, drainage class, and slope-aspect. It does not consider plant competition.

Windthrow hazard. This is based on soil properties that affect the likelihood of trees being uprooted by wind as a result of insufficient depth of the soil to give adequate root anchorage. Depth of the soil may be affected by a fragipan, bedrock, gravel, or a high water table. Differences in root systems related to tree species are not considered. The rating is usually independent of the probability of high winds unless the soil is typically on landscape positions susceptible to high winds.

Plant competition. This is the likelihood of invasion or growth of undesirable plants in openings in the tree canopy. Soil properties such as depth to the seasonal water table and available water capacity have the most affect on natural regeneration or suppression of the more desirable plant species.

Trees to plant. This is a list of one or more adapted species for producing tree crops.

Windbreaks

Windbreaks are made up of one or more rows of trees or shrubs. Well-placed windbreaks of suitable species will protect soil resources, control snow deposition, conserve moisture and energy, beautify an area, provide wildlife habitat, and protect homes, crops, and livestock. The plant species used in windbreaks are not necessarily indigenous to the areas that are planted. Each tree or shrub species has certain climatic and physiographic limits and, within these limitations, a particular species may be well or poorly suited because of soil characteristics. Correlation of soil properties and adaptable windbreak species, therefore, is essential.

A listing of adaptable species is given for each kind of soil where windbreaks will serve a useful purpose—such as open field-planting, interplanting in existing woodland, and for environmental modifications like wind or water barriers and wildlife habitat. The plant species identified for these purposes are stratified by height classes at twenty years of age.

Recreation

Interpretations in heavily populated areas are made for golf fairways, picnic sites, and playgrounds; in sparsely populated areas for paths, trails, and campsites. Interpretations for ski slopes and snowmobile trails are made in some places. Ratings are usually made on the basis of restrictive soil interpretative properties such as slope, occurrence of internal free water, and texture of surface horizons.

Interpretations for recreation must be applied cautiously. Many recreational areas in the United States have only Order 3 or more general soil surveys. Map units for such soil surveys are commonly associations or complexes of soils that may differ markedly in their limitations and suitabilities. Furthermore, general suitability of the map unit must take into consideration not only the qualities of the individual kinds of soil but also the soil pattern and potential interactions. Suitability may depend on a combination of several kinds of soil in a pattern appropriate to the intended use. Finally, factors other than soils are important in recreational planning. Aesthetic considerations, location, accessibility, land values, access to water and to public sewer lines, presence of potential impoundment sites, and location relative to existing facilities may be important even though none of these factors is evaluated for map units.

Wildlife Habitat

Soils influence wildlife primarily through control over the vegetation. Description of the soil as wildlife habitat has two parts. In one part, the suitability class for different vegetation groups is recorded. These vege-

FIGURE 6-5

Ducks in a rice field.

tation groups are called habitat elements. Each habitat element is a potential component of the environment of wildlife. Hardwood trees and shallow water areas are examples of habitat elements. In the other part of the description, soils are rated separately for several kinds of wildlife, including animals adapted to openland, woodland, wetland, and rangeland (fig. 6-5). Current land use and existing vegetation are not considered, because these factors are subject to change and cannot be determined from a soil map. Wildlife population is also disregarded because of the mobility of wildlife and the possibility of a changing population over the year. The ratings show where management for wildlife can be applied most effectively and which practices are appropriate. The ratings may also show why certain objectives may not be feasible; for example, the production of pheasants. Some soil surveys include explicit management recommendations. These may be particularly useful in planning land acquisition for recreational uses.

Construction Materials

Soil survey interpretations estimate suitability of the soil as construction material and show where to locate material that can be mined. Material that compacts readily and has high strength and low shrink-swell potential is preferred as base material under roads and foundations. Gravel and sand are used for concrete, road surfacing, filters in drainage fields, and other uses. Organic soil material is used widely as horticultural

mulch, potting soil, and soil conditioner. Mineral soil material of good physical condition, is generally rich in organic matter and is applied to lawns, gardens, roadbanks, and the like. Soils can be rated as probable sources of these materials. The quality of a particular site, however, usually cannot be specified.

Building Sites

Interpretations are made for the construction of small buildings; for the installation of roads, streets, and utilities; and for the establishment of lawns and the landscaping of the grounds around the building. Such soil uses involve high capital expenditures in relatively small areas. Usually, onsite evaluation is necessary.

Soil survey interpretations are useful for comparing alternative sites, in planning onsite investigations and testing, and in land-use planning. Soil maps can assist in selecting building sites that are near areas suitable for utilities, parks, and other needs.

The preparation of building sites may alter soil properties markedly. To this extent, some interpretative soil properties for the undisturbed sites must be applied cautiously. Upper horizons may have been removed and locally translocated, which might either increase or decrease the depth to horizons important to behavior. The pattern of soil-water states may be

FIGURE 6-6

Damaged house.

FIGURE 6-7

Damaged sidewalk.

changed. Areas may have been drained and, therefore, are not as wet as indicated. On the other hand, irrigation may be employed to establish and maintain vegetation leading to a more moist soil and possible deep movement of water. Pavements, roofs, and certain other aspects of construction increase runoff and may cause inundation at lower elevations where the soil survey does not indicate such a hazard.

Building construction: Construction and maintenance of buildings belongs primarily to architecture and engineering. Additionally, large multistory structures are generally supported by footings placed below the depth of soil survey examination. Soil survey interpretations are not, therefore, a definitive source of information for building construction. Important interpretative soil properties for small buildings and accessory installations such as roads and utilities include slope, inundation, mass movement, potential frost action, depth to bedrock and to cemented pans, shrink-swell, rock fragments >75 mm, erodibility, subsidence, and soil strength (fig. 6-6).

Roads, streets, and utilities: The performance of local roads and streets, parking lots, and similar structures is often directly related to

the performance of the underlying soil, (fig. 6-7). Pipelines and conduits are commonly buried in soil at shallow depth. The properties of the soil may affect cost of installation and rate of corrosion. Soil material is used directly as topsoil, roadfill, and aggregate for concrete. Soil interpretations can predict some suitabilities and limitations of different kinds of soil for these uses, although soil interpretations cannot predict performance of highways, major streets, and similar structures. For such construction, onsite testing is necessary. Use of soil surveys information, however, may reduce the number of borings and engineering tests.

Soil information in conjunction with engineering testing can identify those soils that can be stabilized in place for a road base and establish where gravel or crushed stone will be needed. Soil surveys can be helpful in deciding methods of stabilizing cuts and fills. Soil properties may affect the cost of installation and length of service of buried pipelines and conduits. Shallow bedrock, for instance, greatly increases the cost of installation. Rate of corrosion is related to wetness, electrical conductivity, acidity, and aeration (fig. 6-8). Differences in properties between adjacent horizons, including aeration, enhances corrosion in some soils. Soil properties affect the cathodic protection provided by sacrificial metal buried with pipes. Rock fragments can break protective coatings on pipes. Shrinking and swelling of some soils may preclude the use of certain kinds of utility pipe.

Soil survey interpretations may be particularly useful in the prediction of problems likely to be encountered along proposed routes. Hydrologic information and other data combined with interpretative soil properties, such as the *hydrologic group*, can be helpful for the estimation of potential runoff for design of culverts and bridges. The probability of bedrock and unstable soils that require removal or special treatment can be determined from soil surveys.

Lawns and landscaping: Soil survey interpretations give general information about planning, planting and maintaining grounds, parks, and similar areas. Particularly important is the suitability of the soil for turf, ornamental trees and shrubs, the ability to withstand trampling and traffic, the suitability for driveways and other surfaced areas, and the ability to resist erosion. A number of soil chemical properties may be critical, especially for new plantings. Interpretations for particular plants and the treatments for a specific site require other disciplines.

Many lawn and ornamental plantings are made in leveled

FIGURE 6-8

Corrosion of buried pipe.

areas on exposed subsoil or substratum or on excavated material that has been spread over the ground. Interpretations can be made as to the suitability of such soil materials for lawns and other plantings, the amount of topsoil that is necessary, and other treatments required for satisfactory establishment of vegetation. Highway departments use soil interpretations to establish and maintain plantings on subsoil material in rights-of-way.

Waste Disposal

Waste disposal is divided on the basis of whether the practice places the waste in a relatively small area or distributes the waste at low rates over larger areas of soil.

Localized placement. Waste in this context includes a wide range of material from household effluent, through solid waste, to industrial wastes of various kinds. Effluent from septic tanks is distributed in filter fields. Liquid wastes are stored and treated in lagoons constructed in soil material. Solid wastes are deposited in sanitary landfills and covered with soil material.

The criteria for septic tank absorption fields is given in table 6-1. Extremes in saturated hydraulic conductivity and free water at a shallow depth limit the use of soil for septic tank absorption fields.

Sewage lagoons require a minimum saturated hydraulic conductivity to prevent rapid seepage of the water, a slope within certain limits, and slight or no possibility of inundation or the occurrence of free water at shallow depths.

Soils are used to dispose of solid wastes in landfills, either in trenches or in successive layers on the ground surface. For trench disposal, properties that relate to the feasibility of digging the trench—depth to bedrock, slope—and factors that pertain to the likelihood of pollution of ground water—shallow zone of free water, inundation occurrence, and moderate and high saturated hydraulic conductivity—have particular importance. For disposal on the soil surface, saturated hydraulic conductivity, slope, and inundation occurrence are important.

Low-intensity distribution. Soil is used to render safe, either solid or liquid, waste that is spread on the ground surface or injected into the soil. Manures, sewage sludge, and various solids and waste waters are included, the latter particularly from factories that process farm products. In general, the physical process of distribution of the waste is limited by steep slopes, rock fragments > 75 mm and rock outcrops, and wetness. The rate at which wastes can be applied without contamination to ground water or surface water is called *loading capacity*. Low infiltration values limit the rate at which liquid wastes can be absorbed by the soil. Similarly, low saturated hydraulic conductivity through most of the upper meter limits the rate at which liquid wastes can be injected. Shallow depth of a hardpan or bedrock or coarse particle size reduces the amount of liquid waste that a soil can absorb in a given period. The time that wastes can be applied is reduced by the soil being frozen or having free water at shallow depths. Low soil temperatures reduce the rate at which the soil can degrade the material microbiologically.

Soils differ in their capacity to retain pollutants until deactivated or used by plants. Highly pervious soils may permit movement of nitrates to ground water. Similarly, saturated or frozen soils allow runoff to carry phosphates absorbed on soil particles or in waste deposited on the soil directly to streams without entering the soil. Soils that combine a limited capacity to retain water above slowly permeable layers and a seasonal water excess may allow water that is carrying pollutants to move laterally at shallow depths. Such water may enter streams directly.

Large quantities of waste may change the soil. Heavy loading with liquid waste may reduce the oxygen supply so that yields of

certain crops are depressed. On the other hand, heavy loadings can provide beneficial irrigation and fertilization for other kinds of soil and crop combinations. Animal wastes improve most soils, but the effects differ according to the kind of soil.

The first step in making interpretations of soils for disposal of wastes is usually to determine how disposal systems for each kind of waste have performed on specific kinds of soil in the area. Experience may have been acquired in practical operations or by research. Soil scientists and specialists in other disciplines determine what properties are critical and how to appraise the effects of the properties. Limiting values of critical properties can be determined through experience and may be used in making interpretations where data on soil performance are scarce or lacking.

Water Management

Water management in this context is concerned with the construction of relatively small or medium impoundments, control of waterways of moderate size, installation of drainage and irrigation systems, and control of surface runoff for erosion reduction. These activities may involve large capital expenditures. Onsite evaluation commonly should be conducted, particularly of soil properties at depth. The usual Order 2 or Order 3 soil survey can be helpful in the evaluation of alternative sites, but onsite investigations are required to design engineered projects.

Ponds and reservoirs. Soil information is used in predicting the suitability of soils for ponds and reservoir areas. Impoundments contained by earthen dikes and fed by surface water have somewhat different soil requirements than those that are excavated and fed by ground water. Separate interpretations are commonly made.

Seepage potential of the soil, as determined by the minimum saturated hydraulic conductivity and the depth to pervious soil material, is an important factor for design of ponds and reservoirs. Slope also is of importance because it affects capacity of the reservoir. The *hydrologic group* of the soil (ch. 3) pertains to the prediction of runoff into a pond or reservoir.

Embankments, dikes, and levees. These are raised structures made of disturbed soil material constructed to impound water or to protect land from inundation. The soils are evaluated as sources of material for the construction. Particle size distribution and placement in the Unified system are important considerations. The interpretations do not consider whether the soil in place can support the

FIGURE 6-9

Irrigation of grain sorghum.

structure. Performance and safety may require onsite investigation to depths greater than are usual in a soil survey.

Irrigation. Important considerations for the design of irrigation systems are feasible water application rates, ease of land leveling and the resultant effect on the soils, possibility of erosion by irrigation water, physical obstructions to use of equipment, and susceptibility to flooding. To meet these considerations, an Order 1 soil survey may be needed to include both deeper than customary observations and measurements of infiltration rates. Soil properties that may be the basis for the interpretations are saturated hydraulic conductivity, available water capacity, erodibility, slope, stoniness, effective rooting depth, salinity, sodium adsorption ratio (SAR), gypsum, and properties that may affect the level of response of crops (fig. 6-9).

Interpretations for irrigation in arid and semiarid regions may be more complex than for humid regions, because irrigation changes the soil-water regime more in arid and semiarid areas. Salinity and the SAR of the soils can be particularly significant, as can the quality of the irrigation water. In arid and semiarid areas, small differences in slope and elevation can lead to an accumulation of salt-laden drainage water in low places or the creation of a high water table if a proper drainage system is not provided.

Drainage. The term refers to the removal of excess water from soils for reclamation or alteration. Drainage construction criteria are established by engineers. The criteria include spacing and depth of subsurface drains, depth and width of open ditches and their side slopes, and allowable gradient. Properties of soils important to drainage include water transmission, soil depth, soil chemistry, potential frost action, slope, and presence of rock fragments greater than 75 mm.

Areal Application of Interpretations

The objective of most soil surveys is to provide interpretations for areas delineated on soil maps. This section considers the relationship of interpretations to map unit terminology and conventions, the interpretative basis of map unit design, and the uncertainty of interpretative predictions for specific areas within the map unit.

Map Units

The purpose of this section is to consider the relationships between the terminology and conventions employed to define and describe map units (ch. 2) and soil interpretations. The components of map units are the entities for which interpretations are provided. The application of interpretative information to areas of land must be through map unit descriptions and depends on an understanding of the map unit concept as it applies to interpretations.

Consociations, Associations, and Complexes.—For map units that are consociations, the interpretations pertain to a single, named soil and are applicable throughout the delineation. For *associations* and *complexes* the map unit is named for more than one component. For these kinds of map units the interpretations may be given for each named component or may be given for the map unit as a whole, depending on the objective. Information is commonly provided in the description of the map unit about the geographic occurrence of the named components of the map unit on the landscape. From this information, interpretations for each of the named components of the map unit may be applied to the portion of the landscape on which it occurs. Such an application requires, however, additional information beyond what the soil map alone can provide. The illustrative map unit of Bakeoven and Condon soils (app. I) is a complex of two phases of different soil series. The interpretations are applicable to each of the two phases considered separately. To apply these different interpretations separately requires knowledge of the location of each soil within the map unit delineation. The map unit description will provide information

as to the location and extent of each named component of the map unit.

Map units differ in specificity of the named soils and hence in the broadness of the ranges for various interpretative soil properties. Phases of soil series, for example, are more specific soil concepts than are phases of a higher categorical level. Consequently, in general, the interpretative information for a phase of a soil series has narrower ranges.

Similar Soils.—These are soils that differ so little from the named soil in the map unit that there are no important differences in interpretations. These soils are not named components in the map unit. Recognition is limited to a brief description of the feature or features by which the soil in question differs from the soils in the map unit named. The following statement from the map unit of Sharpsburg soils (app.I) illustrates the point: "In places, the upper part of the material is silty clay. In a few areas, the underlying material contains a few lime concentrations."

Dissimilar Soils.—Map units are permitted to have certain proportions of included soils that differ sufficiently from the named soil to affect major interpretations. These soils are referred to as *dissimilar* (ch. 2). Usually the dissimilarities are such that the soils behave differently. Dissimilar soils are named in the map unit description if they are part of the name of another map unit in the soil survey area. Otherwise, the dissimilar soil is briefly described in a generic fashion: "medium-textured soil with bedrock at less than 50 cm." Location of the dissimilar soils relative to landscape position may be given. Inferences as to the influence of the dissimilar soils on behavior of the map unit may be obtained from their interpretative properties and their location in the landscape. The map unit descriptions may state how the dissimilar soils affect soil behavior. Tabular soil properties and related interpretations do not include properties and interpretations of dissimilar soils. Yield estimates are, in principle, influenced by the occurrence of dissimilar soils if based on field-scale measurement; however, if yields are significantly affected, the "dissimilar" soil would likely be a named component of the map unit.

For map units that are *consociations*, the interpretations pertain to a single, named soil and soils similar to the named soil. Thus, they have a higher possibility of being applicable throughout the delineation than map units named by more than one taxon. For *associations* and *complexes*, map units with more than one component, the possibility of different kinds of interpretations are higher than consociations unless the soils are similar. In these units the interpretations may have to be presented on a probability or possibility basis. Where the soils are related to specific landforms or parts of land forms, interpretations can be related to soils and landforms.

Areal Extension of Interpretations

This may be accomplished by interpreting phases of soil series, as has been historically done, or by modifying the interpretative criteria or models to include the probability of occurrence of properties that affect a certain use. Both of the descriptive approaches that follow require the use of geographic information systems and computer technology to perform the necessary calculations and projections of soil properties areally.

- Phases of soil series have been the principal vehicle to make soil interpretations. Interpretations for the phases of soil series can be extended to map units if adequate information is available to predict the composition of the map delineation. Information on the composition of a map unit and its delineations and a measure of reliability is required. This includes information on composition and properties for included soil series or taxa in a delineation. Interpretations may then be presented in a set of probability statements such as the area has a 60-percent chance of severe limitations for septic tank filter fields because of free water at depths of less than 50 cm. These interpretations could be subdivided further if information is available for soils and landforms in the mapped area. For example, there is a 30-percent chance of moderate limitations on slight rises or knolls for septic tank filter fields because of free water at depths of 50 to 100 cm and a 90-percent change of severe limitations in swales due to free water at depths of less than 50 cm.

- Probabilities for soil properties require that criteria be developed for interpretations that are based on probabilities for occurrence of a limitation. Instead of a criterion that places a severe limitation on soil depth if depth is less than 50 cm, for example, a criterion might be constructed to place a severe limitation if more than 75 percent of an area has soil depth less than 50 cm. In the application of the interpretative model, information on the distribution of basic soil properties is needed for map units and their delineations. Using the data on composition of phases of soil series in a map unit, information on soil properties could be projected from properties of the phase of a soil series.

- Information on the basic soil properties within a map delineation could be collected using a statistical sampling scheme. To do so would require a more intensive field sampling scheme than if properties are projected based on phases of soil taxa and may be feasible for surveys done at a very large scale.

Information presented on a probability basis is essential if risk assessment procedures are to be employed in the interpretation of soils for specific land uses. Coupled with a climatic data base, a probability base presents a powerful method from which to predict soil responses and to develop resource management scenarios.

Areal Generalization

The level of generalization for the application of soil maps and the soil attribute information in soil surveys depends on the scale of the soil map, the taxonomic level used to define the map units, and the combinations of both map scale and taxonomic level. Hole and Campbell (1985) present a detailed discussion of generalizing soil survey information. In the following discussion, these methods of generalization will be discussed. Examples of applications at 3 levels of abstraction are included in the discussion.

Map unit information is commonly generalized from the relatively large scale maps in the soil survey reports to smaller scale maps, but phases of soil series are used to name map units. This is done by combining map units according to landscapes or landforms, physiography, use, vegetation, and geology or climate in order to create smaller scale maps. Such smaller scale maps as the general soil maps in published surveys, historically, use associations of soil series to name the map units.

Generalization of detailed soil maps can also be accomplished by naming or representing the map units at higher levels in the taxonomic system. Detailed surveys commonly use phases of soil series to name map units. This information, however, can be generalized in successive levels by using families, Great Groups, or Suborders to name the map units. This method is rarely used without an accompanying change in map scale.

In addition, generalizations may be made by changing both map scale and level of taxonomic representation. For example, a detailed soil survey (1:24,000 scale) has map units named by phases of soil series. Conversely, a very general map may have small scale such as 1:7,500,000 and map units named at the suborder or order level (highest taxonomic level). Intermediate combinations are possible and must be determined by the purpose for generalizing the information. It may be desirable to have a map scale of 1:7,500,000, but name the map units as associations for phases of soil series. To accomplish this, a method of determining map unit composition from the detailed map must be developed, or the composition is projected from a statistical sampling scheme after Reybold and TeSelle (1989).

Interpretive precision is deliberately sacrificed by cartographic or taxonomic generalization. This is done in order to get a summary map that can provide more general information about larger areas. Once cartographic generalization has taken place, the geographic precision has been sacrificed. For example, a 1:63,360 map that shows associations of phases of soil series is generalized from a detailed soil survey. In this case, the range of properties of each component of a map unit is relatively small. Probability statements for limitations, management needs, and performance of each component can be as specific for the 1:63,360 scale map as for the 1:24,000 scale map; although, the map units for the smaller scale map will have more components, thus diminishing geographic precision for the soil interpretations.

Conversely, on a 1:63,000 map that shows associations of phases of suborders (generalization of scale and taxonomic level), the range of properties of each constituent is large. Limitations and potentials of each constituent can be predicted only in general terms, and interpretations of their effects on use, management, and performance of the map unit must be correspondingly general.

The area of the delineations of interpretative maps should not exceed the area of concern for soil behavior interpretation. Three areas of concern have been given the names *operating units, communities, and regions.* These terms imply relative size of the delineations for which soil interpretations are needed, not to the area represented by the map as a whole.

Operating Units.—These are areas of land that usually are managed as a whole. The most common examples are farms and ranches. The operating units usually range in size from a few hectares to several thousand hectares. In addition to being used by the operators directly, soil maps for such areas are used by farm advisors, credit agencies, planners, and others who are interested in the suitabilities and limitations of soils in individual or contiguous operating units.

The map units usually consist of series or associations of soil series. At least two steps are required to interpret the map units. First, the individual kinds of soil are interpreted and rated for a given use. Then the interaction among the soils and the combined effects of all of the soils on the use, management needs, and expected performance of the mapped area are estimated to arrive at a prediction for the map unit overall. Generally, something is known about the local soil pattern from study locations. This information is used in evaluating portions of map unit delineations that are dominated by particular taxa. For soil maps prepared by generalizing Order 1 or Order 2 soil surveys, local associations of soil series can be easily identified and treated as components of map units.

Local planners use these maps and interpretations to develop recommendations on alternatives for land use, patterns of services, and public facilities. Local planners commonly need ratings of the whole association for alternative uses. Special maps showing the location of areas having similar potentials or limitations for certain uses may be helpful for planners. Information about the amounts and patterns of soils having different potentials within each association can be given in tables or in the text.

Communities.—These areas encompass communities, secondary or tertiary watersheds of major local streams, and other large areas. Map delineations may range from as few as 10 to as many as 1,000 square kilometers. The maps are used for regional planning and other purposes that require consideration of areas larger than individual operating units. In developing countries, maps of this kind are used to identify large areas that are suitable for a specific use. The map units are commonly associations of soil families, subgroups, or great groups. The map unit composition is usually quite heterogeneous. Soil properties, consequently, may have a wide range in most delineations. Soil behavior predictions must be general. The basis for the predictions may be intensive studies of relatively small tracts of land that represent extensive map units.

Soil behavior can be predicted directly from the taxonomic-based characteristics of named soils. An area might be identified as "Argiustoll-Argiaquoll-Haplustoll association on dissected, undulating loess-mantled plains." For each great group, the characteristics that pertain to soil behavior predictions are recorded and evaluations are made. The use, management, and performance of the map unit as a whole is evaluated based on the proportions and geographic patterns of the great groups. The appraisal for the map unit is necessarily general because much of the local detail is unknown.

Regions.—These areas commonly cover continents, large nations, or groups of nations. Soil maps usually have a scale of 1:250,000; although the scale may be as small as 1:1,000,000. The map units are generally associations of soil taxa ranging from the soil series to order levels of taxonomy. These small scale field maps are commonly generalized from soil survey maps at scales of 1:24,000 or larger. The objective of the generalization is to consolidate the soil information of the large areas. For areas that do not have detailed soil surveys, soil maps are made by reconnaissance methods. The information about soils commonly is least abundant and the delineations least precise for Order 5 maps and for schematic maps made without direct field investigations. The units on many maps of regions are associations of suborders, which indicate

many soil properties that are important for broad interpretations. The pattern of soil-water states, for example, can be identified or inferred for suborders such as Udults, Ustults, Xerults, and Aquults. The soil temperature can be identified for some suborders, such as Tropepts and Boralfs. This information can be converted to certain broad interpretations—the kinds of plants that would grow well, for instance.

If such information as relief, physiography, and parent material is contained in the definition of a map unit, then additional interpretations are feasible. For example, the map unit designation "Tropepts and Udults on maturely dissected basalt plateaus" implies information about soil temperature and the pattern of water states, land surface configuration, extractable acidity at depth, and relative fertility of some of the principal soils. Numerous soil behavior predictions about the map unit can be derived from such information.

Behavior prediction at this level must depend heavily on inference. The predictions should be at a level of generalization consistent with the confidence in the original data and in the inferences drawn from them. Soil behavior inferences for map units generalized from more detailed soil maps are more reliable than inferences based on map units formulated without a soil survey.

Illustrative Map Units

Three map units from published soil surveys are illustrated in the appendices: A single soil series (*consociation*), two soil series as a *complex*, and a single taxa above the soil series. Tabular information is given for the map units for which the named soils are soil series. Class limits are in either chapter 3 or chapter 6 or are given directly.

CHAPTER 7 Disseminating Soil Survey Information

Uses of Soil Surveys

Soil surveys most commonly are made for areas that have more than one kind of important land use and for users who have varied interests and needs. These needs may be few and noncomplex in areas of extensive land use where change is not expected or they may be many and complex in areas of intensive land use where changes are expected.

Predictions for uses of soils other than farming, grazing, wildlife habitat, and forestry have tended to concentrate on limitations of soils for the intended uses. Where investment per unit of area is high, modifying the soil to improve its suitability for the intended use may be economically feasible. Soil scientists work with engineers and others to develop ways of improving soils for specific uses. Such predictions are increasingly important in areas where the demand on soil resources is high.

The information assembled in a soil survey may be used to predict or estimate the potentials and limitations of soils for many specific uses. The information must be interpreted in forms that can be used by professional planners and others. A soil survey represents only part of the information that is used to make workable plans, but it is an important part.

The predictions of soil surveys serve as a basis for judgment about land use and management for both small tracts and regions of several million acres. The predictions must be evaluated along with economic, social, and environmental considerations before recommendations for land use and management become valid.

Soil surveys are used to appraise potentials and limitations of soils in local areas having a common administrative structure. Planning at this level is sometimes called *community planning*. It applies to community units—villages, towns, townships, counties, parishes, and to trade areas that include more than one local political unit.

Soil surveys also may be used to evaluate soil resources in multi-county or multi-State areas that have problems that cannot be resolved

by local political units. *Regional planning* deals with land use in broad perspective and appraises large areas. Regional planning is done in less detail than community planning. Soil surveys and their interpretations for regional planning are correspondingly less detailed and less specific. Soil maps and their interpretations for regional planning must provide graphic presentations of the predominant kinds of soil of similarly large areas.

Soil surveys provide basic information about soil resources needed for planning development of new lands or conversion of land to new uses. Failures of trial-and-error land settlements influenced the start of the soil survey in the United States. The use of soil surveys avoids the waste caused by ignorance of soil limitations when major changes of land use are contemplated or when new lands are to be brought into use.

Soil survey information is important in planning specific land use and the practices needed to obtain desired results. For example, if recreational use is being considered, a soil survey can indicate the limitations and potential of the soil for recreation. The soil survey can help a landscape architect properly design the area. A contractor can use the soil survey in planning, grading, and implementing an erosion control program during construction. A horticulturist can use it in selecting suitable vegetation.

Soil surveys provide a basis for decisions about the kind and intensity of land management needed, including those operations that must be combined for satisfactory soil performance. For instance, soil survey information is useful in planning, designing, and implementing an irrigation system for a farm. The kind of soil and its associated characteristics help in determining the length of run, water application rate, soil amendment needs, leaching requirements, general drainage requirements, and field practices for maintaining optimum soil conditions for plant growth.

Soil surveys are also useful in helping to locate possible sources of sand, gravel, or topsoil. They are an important component of technology transfer from agricultural research fields and plots to other areas with similar soils. Knowledge about the use and management of soils has been spread by applying experience from one location to other areas with the same or similar soils and related conditions.

The hazards of nutritional deficiencies for plants, and even for animals, can be predicted from soil maps if the relationships of deficiencies to soils have been established. In recent years, important relationships have been worked out between many soils and their deficiencies of such elements as copper, boron, manganese, molybdenum, iron, cobalt, chromium, selenium, and zinc. The relationships between soils and deficiencies of phosphorus, potassium, nitrogen, magnesium, and sulfur are widely known. Relationships of soils to some toxic chemical elements have also

been established. By no means have all of the important soils been characterized, especially for the trace elements. More research is needed.

Land appraisal.—Soil is one of the many attributes of land that contribute to its value. The relative importance of soil varies widely among the many uses of land. Where the soil is a factor of production, as in farming, ranching, or forestry, its capacity to produce and its requirements for production are elements of land value.

Soil surveys provide information in terms of soil qualities that bear directly on land value for many different purposes. These interpretations are used most often, however, in assessing farmland for taxation and equalization, in appraising land for loans, and in guiding land buyers.

The soil is only one of the elements that must be considered for appraisal of land value within the local, economic, and institutional environment of an area. Many of the other elements that determine value of real estate can change with time. The recorded kinds of soil in a soil survey, however, remains valid over time and can easily be reinterpreted as economic or institutional conditions change.

Other uses.—In addition to the above mentioned widely recognized uses, soil surveys serve other purposes.

Soil surveys commonly provide essential data and information for the compilation of general soil maps. Many soil surveys are done for purposes that require relatively intense field investigation and map scales of about 1:12,000 to 1:24,000. A smaller scale soil map, however, with more broadly defined units may be better for developing land-use plans for large areas. This map can be made by grouping units of the large-scale soil maps and generalizing the map detail. The resulting map units are more useful for the intended use. The selected scale of the general soil map is usually the same as that of the land-use planning map.

Soil surveys also provide information for compiling soil maps for areas that are largely unsurveyed. These maps are made by predicting the kinds of soil in an area from existing information, largely or entirely without the benefit of preexisting soil survey maps or field investigations. Scattered soil surveys in these areas provide some soil information that can be projected to unsurveyed areas by photo interpretation or by predicting the occurrence of kinds of soil from related climatic, topographic, geologic, or vegetative features.

Soil surveys have served as a basis for educational programs to inform people of the important place soil resources have in maintaining a quality environment.

Small-scale soil maps provide a basis for comparison of broadly defined capabilities and limitations that relate to the soil on regional, national, and even worldwide scales. International cooperation among

soil scientists has accomplished much in relating the different soil classification systems of various countries to one another using small scale maps. This permits extending the findings of research on soils of one country to similar kinds of soil elsewhere. *Soil Taxonomy* (1975) and the *Soil Survey Manual* (1951) have guided soil scientists worldwide for many years. Many have contributed ideas and data to form the basis of the soil survey system. As a result, the uses of soil survey data have been extended far beyond the boundaries of the countries where data were originally obtained.

The results of soil surveys are published to provide the public with the soil information it needs to make sound decisions about land use and management and to provide a permanent record of what has been learned about soils. The soil survey is the key element in planning both agricultural and nonagricultural uses. Much of the information is spread by soil scientists, conservationists, and other agricultural workers in day-to-day contracts. This chapter discusses other methods used to disseminate soil survey information.

Making Information Available

In the United States the information assembled in a soil survey is public property. Computer data banks of basic soil survey data are also public property and are available to workers in soil research and land use management.

Technical information about soils for both nontechnical and technical users appears in special reports and professional publications and in bulletins and circulars issued by agricultural experiment stations or other government agencies. Popular media also release timely information.

The first obligation of a soil survey party is to complete the fieldwork and assemble the information for the final publication of a survey. The soil survey work plan, however, should provide reasonable extra time to allow the survey party to satisfy any obligations it may have to collect specific information for particular groups or individuals.

The *National Soil Handbook*, particularly the section on the descriptive legend, is the primary reference material used while a survey is in progress. The descriptive legend identifies the symbols that appear on the soil maps and describes the map units they represent. The legend provides the means by which the survey leader maintains accuracy and uniformity in mapping and is a primary source of information for public use before the survey is published. The completed field sheets and the descriptive legend together provide a ready reference about the kinds of soil and their basic properties where mapping has been done. As the sur-

vey progresses, various kinds of interpretations are made for the soils of the area. The interpretations, along with the descriptive legend, gradually become a preliminary draft of the published soil survey. While the survey is in progress, technicians apply soil survey information from the Handbook and make the information available to the general public. The staffs of all of the cooperating agencies should have access to the descriptive legend and other references.

The survey party commonly receives requests to prepare interpretative maps and text for special purposes while a survey is in progress. For example, a town planning board may ask that its township be completed and a special interpretative report be made for the board's use. Such a report is time consuming and costly; therefore, appropriate allowances of time and arrangements for financing this service should be listed in the soil survey work plan.

Even though the published soil survey is the principal medium for disseminating soils information, it cannot include detailed interpretations for all of the various uses of soils. Special interpretations often are needed after a soil survey has been published. The published soil survey becomes the repository for the basic data on which the various agencies depend.

The data collected for a soil survey are published in a variety of forms under the authorship of an individual or a group. The information is of special interest to the scientific community and appears in general articles, bulletins, and releases. The data collected for soil surveys and special investigations are readily available to all scientists.

A soil survey commonly draws on the data and experience of experts in other disciplines, including direct collaboration of scientists in other fields. Any release of information should acknowledge the source of supporting data and assistance and cite published material from which interpretations have been drawn. The contributions of individuals who have collaborated must be acknowledged.

Soil Survey Publications

Soil survey reports are the primary means for disseminating the information gathered by the National Cooperative Soil Survey in the United States. These publications commonly cover a county or a particular part of a State. They may cover two or more counties or only part of one or more. The area covered by a survey is determined by many factors, including complexity of soils, topography, and the needs of users.

Besides the formal soil survey report, special summaries of soils information for the survey area may be required. Information may be

needed before the formal report is finished, or new information may be needed after the report has been released. Special reports are often useful to present information on specific topics.

Many people and agencies contribute to the making and publishing of soil survey reports. Local, State, and Federal cooperators may provide funds and personnel for the survey. The central responsibility for coordinating the individual soil surveys, as well as the national soil survey program in the United States, rests with the Soil Conservation Service.

Soil survey publications are distributed widely, although most of the copies of a survey are distributed in the area covered by that survey. Publications are distributed by the cooperating agencies and the local conservation district. Publications are also available from Members of Congress. The Extension Service conducts educational programs about the use of soil surveys. Published soil surveys are available in libraries of most universities and colleges in the United States and in libraries of many towns and cities. In addition, they are distributed to agricultural colleges, ministries of agriculture, and libraries in many other countries.

Followup.—Feedback from soil survey users in both the private and the public sectors helps to evaluate soil survey information and to decide whether additional kinds of information are needed and whether the content and format of soil survey publications should be changed. Feedback from users may reveal new ways to disseminate soil survey information and suggest adjustments in the objectives and design of soil surveys.

The Texas staff of the Soil Conservation Service sends out a questionnaire for each soil survey report about a year after it has been published and distributed. The questionnaire, sent to a cross section of potential users, is designed to determine who uses the soil survey information and how it is being used. It also is designed to obtain suggestions from users on how to make the information more helpful. It asks about the kinds and amount of media coverage, meetings, and other activities used to promote the new publication.

Soil Survey Reports

The soil survey report provides a permanent record of what was learned about the soils of a survey area. In addition to a map showing the distribution of the different kinds of soils in the area, the publication describes the soils and summarizes research that has been done on the effects of soil on plants and engineering practices.

The text provides descriptions, laboratory data, and other information about the properties of the soils. From these basic data, interpretations are made about potentials, suitabilities, and limitations of the soils for crops, pasture, forest, wildlife habitat, recreation, engineering, and

any other uses known to be important at the time of the survey. The interpretations and predictions are based on an up-to-date understanding of soils. Discussions of land use and management are written to bring out specific relationships to individual soils or groups of soils shown on the map.

The properties, responses to management, and suitabilities and limitations of each kind of soil are given to enable the public to make full use of the soil map, whether for producing crops or for locating building sites or sources of construction material. Predictions are made of the behavior of each kind of soil under specified uses and management systems. Predicted yields under defined systems of management and use are also provided. The use of a soil classification system permits eventual development of many useful interpretations beyond those required for the immediate objectives of the survey.

A published soil survey contains instructions for its use, information about how the survey was made, an account of the general nature of the area, a description of the general soil map, a classification of the soils, a discussion of soil formation, references, and a glossary.

The form and content of the publication depends on the nature of the area surveyed, local conditions and needs, and the kinds of uses anticipated. The contents are arranged so that the user can find information as conveniently and rapidly as possible. Data and interpretations are assembled in tables to bring out relationships and contrasts among soils.

Interim and Supplemental Reports

Occasionally, soil survey information is requested before a survey can be published. In such cases, an *interim report* may be issued. An interim report is not needed if only a few people request the soil survey information.

An interim report may cover townships, metropolitan areas, shoreline areas, strips along highways, or large parts of a survey area. A limited number of copies of the report are printed. The groups and agencies that require the report commonly contribute toward the cost of preparing it and participate in its distribution. The report generally contains reproductions of soil survey field sheets, descriptions of the map units, and interpretations for the important uses. Those who use the information in an interim report must be cautioned that the information is tentative and may be revised.

Updating or expanding interpretations, making additional interpretations, or mapping parts of the survey area in greater detail may be desired after a survey has been published. Revised information is commonly needed where land use is changing significantly, such as areas of rapidly expanding population. The new information can be dissemi-

nated in *supplemental reports*. If a part of the survey area is mapped in greater detail, reproductions of the new field sheets and descriptions and interpretations of the new map units are included.

The Soil Survey of Durham County, North Carolina, was published in 1976 (USDA, SCS, 1976). Within a few years, it became apparent that those working with the design, installation, and maintenance of sewage disposal systems needed more information on rating soils for absorption of sewage effluent. The supplement, issued in 1981, contains graphic models that compare soil criteria for conventional systems with those for two other systems. It also contains profile sketches of soils that depict the major features that adversely affect the use of the soils for absorption of sewage effluent.

Another example of expanding existing interpretations is the supplement to the published Soil Survey of Comanche County, Oklahoma (USDA, SCS, 1982). Although the original soil survey interpreted the soils for agricultural and nonagricultural uses, more detailed information was needed. The supplement provides soil potential ratings that reflect not only the performance or productivity of the soils and the limitations of the soils for selected uses but also takes into account the corrective measures needed to overcome the limitations and the cost of the corrective measures.

The supplement to the published Soil Survey of the San Diego Area, California (Bowman, 1973), shows some innovative ways of presenting updated and more detailed soil interpretations for a survey area that has experienced a tremendous population increase and extensive urban growth (San Diego County, CA Planning Dept., 1975). The supplement includes text and tables of soil interpretations that can be applied to farming, ranching, land management, construction, and to urban and recreational uses.

Special Reports

Special interpretative reports can be prepared on the suitability and limitations of the soils for a single use. Other special reports integrate soils data from sources other than SCS survey teams.

The "Red Tart Cherry Site Inventory" for Leelanau County, Michigan, is an example of a report interpreting the soils for a specific use (USDA, SCS, 1973). Soils were evaluated on a "fruit site rating sheet" based on soil, physiographic, and climatic factors for growing red tart cherries. The soils information came from the Soil Survey of Leelanau County. Boundaries of the red tart cherry sites are outlined on a set of inventory map sheets. The sites are color-coded to indicate the difficulty of overcoming the limitations to production.

"Soil Potential Ratings for Septic Tank Absorption Fields, Northeastern Illinois" provides home buyers, planners, installers of septic systems, and sanitary engineers a guide that indicates the relative potential of every soil as septic tank absorption fields in the area of the six counties (USDA, SCS, nd). It aids in site selection, community planning, and subdivision design where septic tank absorption fields are considered.

The special report "Alaska Agricultural Potential" is based on a cooperative study by more than a dozen State and Federal agencies (ARDC, 1977). It was developed as a basic reference in response to rapidly accelerating interest in and need for information on Alaska's land and natural resources. It has text, tables, and interpretative maps.

"America's Soil and Water: Condition and Trends" is an example of a special report that used text, charts, graphs, and national interpretative maps to present a brief account of our basic resources (USDA, SCS, 1980).

A special report for Pennsylvania, "Chester County Natural Environment and Planning," analyzes the natural environment in terms of landforms, soils, geology, woodland, and climate (PA Planning Comm., 1963). The section on soils includes text, a general soil map, and a series of colored interpretative maps.

The pocket-size book "Soil Resource Inventory, San Mateo Mountains, Magdalena Ranger District, Cibola National Forest" interprets the soils for multiple-use planning and management (USDA, FS, 1975). It includes a landscape photograph and a description of each map unit, tables that interpret the map units for a number of uses, and a soil map at the scale of 1 inch to the mile.

"Soil Resource Inventory for the Umatilla National Forest" provides land managers with the necessary soil interpretations for extensive management and resource planning (USDA, FS, n.d.). This report gives the description of and the interpretations for any map unit adjacent to any map sheet.

"Natural Soil Groups of Maryland" is part of the technical series of the Maryland Department of State Planning, which deals with the development of a generalized land-use plan for the State (MD Dept. State Plan, 1973). This publication is designed as an interpretative guide to the detailed soil survey maps. Map units, listed by counties, are assigned to natural soil groups (groups of soils that have similar major properties and features). A large table shows color-coded ratings of natural soil groups for selected uses. Natural soil group maps, which are not included with this publication, are generalized from the detailed soil maps. A separate map is made for each county.

General Soil Maps

General soil maps provide an overview of the location and extent of the dominant soils in a large area. General soil maps are useful in showing the soils in community areas, counties, States, and other large areas. They are most useful in general planning and in locating areas that have the soil properties needed for a specific land use, such as a site for an industrial plant. The general soil map can help in narrowing the field of search, but it is not precise enough to fix an exact location for the plant.

General soil maps commonly are derived from detailed soil maps by combining their delineations from units that are more extensive but less homogeneous (generalized soil maps). Where detailed information about soils is lacking, general soil maps can be compiled from knowledge about features related to soils—geology, climate, vegetation, topography—and principles of soil genesis.

The amount of information that can be given about the units on a general soil map—and, therefore, the interpretations that are feasible—depends on the degree of generalization of the map units. The degree of generalization is determined by the scale of the map. A general soil map at a scale of 1:100,000 can show associations of soil series, so the features of those series can be used in developing interpretations. By contrast, a general soil map at a scale of 1:1,000,000 can show only associations of subgroups, and only phase criteria that are characteristics of subgroups can be conveyed to the user. From the latter map, the feasible interpretations are much fewer and less specific than those developed from a large scale map. For a discussion of schematic soil maps, see chapter 2.

The text that accompanies the general soil map includes identification of the components of map units and a description of their physical setting. The most useful texts also include percentages of the components, characterizations of the soils, and interpretations that give the limitations and suitabilities of the soils for various agricultural and nonagricultural uses.

Generalized Soil Maps of Survey Areas

Generalized soil maps published as part of detailed soil surveys in the United States usually have a mapping scale between 1:63,360 and 1:316,800 with even inch and mile increments, such as 1 inch equals 3 miles or 1:190,080. The scale is determined by the expected requirements of the user, by the size of the survey area, and by restrictions imposed by compilation and printing. The map units commonly are associations of soil series.

Legends vary considerably among maps of survey areas; they may give the underlying material, landforms, soil texture, depth to bedrock, and drainage. Detailed descriptions of the map units, soil profile descriptions, and evaluations of limitations and suitabilities for agricultural and nonagricultural uses are given in the accompanying report.

Generalized soil maps are used to make planning policy decisions for large areas—for community planning, for identifying management problems common to extensive areas, and for general educational purposes where a broad overview of the soil is needed. These maps are not suitable for farm and ranch planning or for site evaluation.

General Soil Maps of States

State maps are similar in many parts to the generalized soil maps in published soil surveys; other parts may be similar to schematic soil maps. Many State general soil maps have been published at scales of 1:1,000,000 to 1:1,500,000; they range from 1:300,000 to 1:3,000,000. Map units generally are associations of soil series, although associations of higher taxa have been used on some maps.

The legends are similar to those of the generalized soil maps of survey areas. Explanatory text for most State maps is brief. For some the text is limited to what can be printed in the margin of the map or on the back of the map sheet. On the other hand, some maps are accompanied by a booklet that includes both basic information and interpretations. "Soils of Tennessee" contains descriptive text interpretations for the State general soil map, which is folded in a pocket at the back of the pamphlet (Springer and Elder, 1980).

These general soil maps provide an overview of the distribution of the more extensive soils of the State. They are useful in planning broad land use for multiple-county and statewide areas and aid in the identification of broad areas that have features suitable or unsuitable for a variety of purposes. They are also useful in the transfer of technology between areas of similar soil environments. They can be used to identify areas for which more detailed information should be collected, and they aid the study of soils and their environment.

Regional and National Soil Maps

Maps of the soil pattern of large areas in terms of a relatively few kinds of soils are compiled by generalizing more detailed soil maps and information about them; they are also compiled in part on the basis of inferred properties determined by interpreting information about geology, climate, vegetation, and topography. The scale is commonly smaller than 1:1,000,000.

Units on regional and national maps are usually associations of great groups or suborders. Accompanying descriptive material is usually brief, as in the *National Atlas of the United States of America* (DOI, USGS, 1970). Some regional maps have accompanying booklets.

General soil maps at the small scales of regional and national soil maps are used for studying very broadly defined capabilities and limitations that affect regional and national issues. They are useful in relating areas of similar soils for transferring technology and exchanging research results. Interpretations for broad land uses and estimates of limitations and suitabilities can be made to the degree permitted by the scale of the map and the heterogeneity of the map units.

The map "Soils of the Southern States and Puerto Rico" is based on soil surveys and research by State and Federal agencies (Buol, 1973). The map is organized at two levels of generalization—soil orders and associations of great groups. The text discusses each soil order of the region, including its geography, landscape, relief, vegetation, land-use considerations, and soil mineralogy, as well as the distinguishing features of the major soils in the order. This publication facilitates the interchange and application of research findings across State borders and provides general information on the region.

Technical Reports

Some technical soil survey information is used mainly by workers in soil science and in related fields. This information is recorded in technical papers, theses, and dissertations, many of which are published in technical report series and summarized in professional journals.

Soil survey investigative reports.—The Soil Survey Investigation Reports, published by the U.S. Department of Agriculture, Soil Conservation Service, makes technical information available from cooperative laboratory and field investigations of soils of the 50 States, Puerto Rico, and the Virgin Islands. Some volumes contain physical, chemical, and mineralogical data from soil laboratories and descriptions of the profiles that were sampled. Others report studies of the genesis of significant soils in a particular area.

Before Soil Survey Investigative Reports were started, laboratory data were distributed in unpublished form to those immediately concerned with specific problems. Some data appeared in technical journals, regional or national technical bulletins, or published soil surveys; however, much of the data was not readily available.

Some experiment stations issue summaries of available data on soils within their States. These summaries are issued periodically as data accumulate and are available to those who need it.

Technical monographs.—Monographs summarize the existing data and provide additional data for as nearly complete an understanding of the genesis, morphology, and classification of the subject soils as possible. A technical monograph generally deals with the dominant soils of a comparatively large area, such as a major land resource area. In such areas, the dominant soils are broadly similar in genesis and morphology.

Technical monographs differ somewhat in form and content from one area to another. Generally, a monograph contains an introduction that gives pertinent geographic information, a small-scale soil map with explanation, general and detailed description of the soils, laboratory data for soil characterization, and a thorough discussion of the classification of the soils. "The Desert Project Soil Monograph" is an example (Gile and Grossman, 1979).

Reports on benchmark soils.—A benchmark soil is one that, because of its great extent or its key position in the soil classification system, is important in determining properties and interpretations of the soils in a large area. The information obtained about benchmark soils can be extended to closely related soils. These reports are usually cooperative efforts among State agencies and the Soil Conservation Service. Many of the reports are published by the experiment stations.

Reports on benchmark soils generally contain a summary of location and extent of the soils and a summary of suitabilities of the soils for use. The body of the report contains laboratory data, detailed descriptions of selected profiles, crop-yield data and predictions for defined management systems, a discussion of the use of the soil for engineering and a table of engineering properties, and a fairly detailed discussion of management of the soils for the various uses to which they are suited. There is also a review of the problems related to management and an outline of methods for solving such problems. For an example, see "The Charlton Soils" (Hill and Shearin, 1969).

Scientific papers.—Papers and reports on special studies about soils record the procedures used and the results obtained. For the most part, these papers are presented and distributed at professional meetings. Many of the papers are published in professional journals and similar publications. These papers not only keep soil scientists up-to-date on soils information, but they are also helpful to scientists in other disciplines. Some papers integrate soil data with data of other disciplines and are published in the journals of those fields.

Other publications.—Soils information appears in publications other than soil survey reports. For example, the Soil Conservation Service has published reports for resource conservation and development projects, river basin studies, flood hazard analyses, and small watershed projects.

These reports, as a rule, contain considerable information about the soils of the area covered in the project.

A special technical publication, "Soil Classification in the United States," records and partly explains the changing concepts that have guided soil classification through its various stages of development in the United States (Cline, 1979). It assembles the various attempts at classification of soils, emphasizing those developed after the system was presented in the 1938 Yearbook of Agriculture.

Popular Media

Government agencies issue publications to inform the general public about common soil problems and to explain how the soil survey can help people to avoid or solve such problems. Some publications discuss soil problems broadly and are aimed at people who are not familiar with the information available in soil surveys. Other publications are directed toward certain groups, such as farmers, or homeowners. These publications explain specific soil-related problems and tell how to avoid or solve them.

Indiana's pamphlet "Adaptability of Various Tillage-Planting Systems to Indiana Soils" is intended to help managers determine which tillage system and what combination of equipment are best for their particular soils, climate conditions, and farming operations (Galloway et al., 1977). Arable soils are assigned to tillage-management groups, and these groups are rated for nine tillage-planting systems, including no-till.

"Yield Estimates for the Major Crops Grown on the Soils of West Tennessee" estimates yields for the major crops of the area under currently recommended technology and production practices (Buntley and Bell, 1976). It also discusses the soil factors that affect crop yields.

"Soil Productivity in Illinois" shows the average yields of various grain, forage, and tree crops obtainable under basic and high-level management (Univ. Illinois, Coll. Agric. Coop. Ext. Serv., 1978). It consists of text, graphs, and tables. Productivity indices are given for the soils, and a simplified method of adjusting both yields and productivity indices for slope and erosion phases is provided for the two levels of management.

Photographs and captions in the bulletin "Using Soils as Ecological Resources" explain how some soil properties affect the usefulness of particular soils (Olson, 1971). This bulletin also illustrates some of the ways that soils information can be applied to land-use problems. The bulletin is an adaptation of a slide presentation developed for New York.

The bulletin "Soils of the Southeast Missouri Lowlands" shows some innovative ways of arranging soils by pH value and texture of the

surface layer and then putting together data on soil properties significant to agronomy (Univ. Missouri, 1978). This publication has a general soil map, block diagrams with brief soil descriptions, text, and tables.

"Water for Nevada" describes the use of a reconnaissance soil survey of a large desert basin to determine enough facts about the common soils to evaluate their potential for irrigated agriculture, for engineering works, and for the application of certain range improvement practices on a planning basis (Univ. Nevada Agric. Exp. Sta., 1971). A detailed study of such a large and unknown area would have been prohibitively expensive and slow.

Displays are a useful way to pass along information about soils. Displays can be set up at State or local fairs or in offices, libraries, or store windows. These displays are particularly effective in showing relationships between soils and natural vegetation or between soils and land-use management. Displays are also effective in illustrating soil features, such as depth to layers that restrict plant roots and characteristics of specific layers. The display should contain no more information than can be absorbed in a few minutes. Displays at fairs should have a soil scientist or conservationist present to answer questions. Place mats in restaurants also are effective in disseminating soil survey information because they reach a cross section of the population.

Local newspapers generally follow a soil survey as the work progresses and report the release of the published soil survey. Some newspapers also print articles about the application of information in soil surveys to local use and management problems. Some newspapers will carry a feature story about a different soil each day or each week. Such articles are written by local soil scientists to appeal to the general reader. Periodicals of wider circulation occasionally contain articles dealing with widespread soil problems and tell how soil survey information can be applied in solving these problems. Television and radio can tell a large audience about experiences with soil-related problems.

Automated Soil Data Bases

Soil survey information lends itself well to automation. Most information about a single soil phase is applicable to the phase wherever it is mapped. The computer allows soil data and soil interpretations to be entered edited, stored, manipulated, and retrieved in various formats quickly and accurately. Soils information can be given to the public more quickly than ever before.

Soil Interpretations

Soil interpretation records in the United States are stored in a national computer data base. This data base produces:

- interpretations of phases of soil series, including estimates of selected soil properties; limitations for various uses; capability classifications; yields of crops and pasture; and interpretations for woodland, windbreaks, wildlife habitat, and range;

- interpretative tables in various formats, including most of the tables used in published soil surveys and technical guides;[1] and numerous other tables of soil properties for evaluating soils for irrigation, drainage, and other purposes.

The name and acreage of every soil survey map are stored by survey. The major land resource area and interpretation number for each unit are also stored. This permits the retrieval of lists for many different kinds of users. For example, the map units may be sorted and printed out by major land-resource area, by a specific feature (such as being well drained), or by a specific soil interpretation (such as having only slight limitations for the disposal of septic effluent).

Physical, chemical, and mineralogical laboratory test data are stored for reference and support in soil correlation, classification, and interpretation. Descriptions of the analyzed profiles also are stored. These data contribute significantly to the understanding of soil genesis, soil-landscape relationships, and soil behavior.

Also included in the national computer data base is the classification of all soil series and official series descriptions, which helps in maintaining the consistency and integrity of the classification system. The information in this file can be manipulated to obtain such groupings as all soil series in a particular category of classification.

Computer Storage of Soil Maps

More soil survey maps are being stored in a computer. Soil boundaries are input by digitizing and are referenced to a State plane coordinate system. Soil areas (cells) are identified by name. The computer allows the soil information to be edited, revised, manipulated, and retrieved in various scales quickly and accurately. Computer stored soil information

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[1]These tables provide estimates of soil properties, suitability, and limitations of soils for selected uses and predictions of yields of selected crops and pasture plants.

can be a part of a Geographic Information System (GIS) or can be used to provide output in the form of graphic thematic maps and statistical data. A GIS is a very effective means of using soil information. The system integrates soil data and other resource relational data bases for the needs of a specific user.

Three kinds of thematic maps have been prepared through computers:

- county interpretative maps, such as the "Soil Blowing Hazard" map for McClean County, North Dakota, and the "Source of Sand" map for Brevard County, Florida;

- watershed area interpretative maps, such as "Hydrologic Soil Groups" for Chickies Creek Watershed Area, Lancaster County, Pennsylvania, and the "Cropland by Capabilities" map for the Loosahatchie and Wolf Rivers Watershed in Tennessee and Mississippi; and

- special area maps, such as the city of Garrison, McClean County, North Dakota.

Other subjects that have been selected for computer-generated maps include important farmland, land capability classes, slope, potential for dwellings with basements, potential for disposal of septic effluent, crop production, and soil erodibility.

A pilot project in North Carolina (Computerized Soils and Interpretive Maps, n.d.) tested the feasibility of automating the manual steps of soil map drafting. Several interpretative maps were made of a 7.5-minute quad soil survey map from the published soil survey of Jones County, North Carolina.

"Using Soil Surveys Through Interpretive Maps" illustrates how computers can be used to store information, assemble the data for interpretations and predictions, and provide maps at the size and scale requested (USDA, SCS, n.d.).

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APPENDIX 1 Series Data

Three appendices are included. The first gives examples of descriptions of soil series. The second describes three map units that are quite different in their systematics. The third appendix contains point information for soils of the three map units.

Sharpsburg Official Soil Series Description

The Sharpsburg series consists of deep, moderately well drained soils formed in loess on uplands. Permeability is in the moderately high saturated hydraulic conductivity class. The lower part of the subsoil is more permeable than the upper part. Slope ranges from 0 to 18 percent. Mean annual temperature is about 11 °C, and mean annual precipitation is about 750 mm.

Taxonomic Class: Fine, montmorillonitic, mesic Typic Argiudolls

Representative Pedon: Sharpsburg silty clay loam with a convex slope of 8 percent—cultivated. Colors are for moist soil unless otherwise stated.

Ap—0 to 20 cm; black (10YR 2/1) silty clay loam, dark grayish brown (10YR 4/2) dry; weak fine subangular blocky structure; friable; few fine roots; slightly acid; abrupt smooth boundary.

A1—20 to 28 cm; very dark brown (10YR 2/2) silty clay loam, dark grayish brown (10YR 4/2) dry; moderate very fine subangular blocky structure; friable; slightly acid; clear smooth boundary.

A2—28 to 43 cm; very dark grayish brown (10YR 3/2) silty clay loam, grayish brown (10YR 5/2) dry; some brown (10YR 4/3) peds; moderate very fine subangular blocky structure; friable; moderately acid; gradual smooth boundary. Combined thickness of the A horizons is 25 to 60 cm.

Bt1—43 to 61 cm; brown (10YR 4/3) silty clay loam; very dark gray (10YR 3/1) coatings on faces of peds; moderate fine subangular blocky structure parting to weak fine subangular blocky; firm; common distinct very dark grayish brown (10YR 3/2) clay films; very few fine roots; moderately acid; gradual smooth boundary.

Bt2—61 to 79 cm; brown (10YR 4/3) and yellowish brown (10YR 5/4) silty clay loam; few fine prominent light brownish gray (2.5Y 6/2) mottles; weak medium prismatic structure parting to moderate fine subangular blocky; firm; many distinct dark grayish brown (10YR 4/2) clay films; very few fine and medium roots; few fine dark concretions (iron and manganese oxides); moderately acid; gradual smooth boundary.

Bt3—79 to 97 cm; brown (10YR 5/3) silty clay loam; common medium distinct light brownish gray (2.5Y 6/2) and strong brown (7.5YR 5/6) mottles; weak medium prismatic structure parting to weak medium subangular blocky; friable; many prominent grayish brown (10YR 5/2) clay films; few fine dark concretions (iron and manganese oxides); moderately acid; gradual smooth boundary. Combined thickness of the Bt horizons is 53 to 97 cm.

BC—97 to 117 cm; yellowish brown (10YR 5/4) silty clay loam; many fine and medium distinct grayish brown (2.5Y 5/2) and common medium prominent strong brown (7.5YR 5/8) mottles; weak medium prismatic structure; firm; common distinct grayish brown (10YR 5/2) clay films; few fine dark concretions (iron and manganese oxides); moderately acid; gradual smooth boundary. (10 to 25 cm thick)

C—117 to 152 cm; mottled grayish brown (2.5Y 5/2), yellowish brown (10YR 5/4), strong brown (7.5YR 4/4) silty clay loam; massive; firm; very few fine roots; common fine dark concretions (iron and manganese oxides); slightly acid.

Type Location: Taylor County, Iowa; about 13 km north and 8 km east of Bedford; 570 m east and 165 m south of the northwest corner, sec. 10, T. 69 N., R. 33 W.

Range in Characteristics: Solum thickness typically is 90 to 180 cm thick. Thickness of the A horizon, depth to clay maximum, maximum percent clay, thickness of the Bt horizon, depth to grayish mottles, and solum thickness decrease as gradient increases on convex slopes. The solum is moderately acid or strongly acid in the most acid part.

The Ap horizon has value of 2 or 3 and chroma of 1 or 2. The A1 and A2 horizons have value and chroma of 2 or 3. The A horizon ranges from 25 to 34 percent clay.

The upper part of the Bt horizon has value of 4 or 5, and chroma of 3 or 4 and contains 36 to 42 percent clay. Pedons having colors in the matrix of 5 or 6 value and 2 chroma at depths of less than 80 cm are outside the range.

The lower part of the Bt horizon, the BC horizon, and the C horizon have hue of 7.5YR to 5Y, value of 4 through 6, and chroma of 2 through 6. The C horizon is silty clay loam or silt loam.

Competing Series: These are the Gymer, Oska, and Polo series. Similar soils are the Grundy, Macksburg, and Wymore soils. Gymer and Oska soils have 7.5YR or 5YR hue in the Bt horizon. In addition, Oska soils have a lithic contact within depths of 100 cm. Polo soils have 7.5YR and 5YR hue in the lower part of the B horizon. Grundy and Macksburg soils have lower chroma, mottles, or both in the upper part of the B horizon. Also, Grundy soils have 42 to 48 percent clay in the upper 50 cm of the argillic horizon. Wymore soils have 2.5Y or yellower hue, dominant chroma of 2 in the B horizon, and contain more clay.

Geographic Setting: Sharpsburg soils are on convex ridgetops, and convex side slopes, and on high benches. Typically, they are on narrow ridgetops having slopes of 2 to 9 percent gradient. The full range of slope is from 0 to 18 percent. Sharpsburg soils formed in 2 to 5 meters of loess that contains less than 5 percent sand. Mean annual temperature ranges from about 8 to 14 °C and mean annual precipitation ranges from about 700 to 800 mm.

Geographically Associated Soils: The somewhat poorly drained Macksburg soils and the poorly drained Winterset soils form a drainage sequence with the Sharpsburg soils and commonly are on the more nearly level parts of the landscape. Adair, Clarinda, Lamoni, Pawnee, and Shelby soils are on adjoining lower parts of the landscape. They formed in till or in paleosols formed in till. Judson soils are on foot slopes downslope and formed in local colluvium. Clearfield and Nira soils are nearby at about the same elevations and have a grayish B horizon.

Drainage and Permeability: Moderately well drained. Surface runoff is medium to rapid (Soil Survey Staff, 1951). Permeability (saturated hydraulic conductivity) is in the lower half of moderately high in the upper part of the subsoil and in the upper half of moderately high in the lower part and in the substratum.

Use and Vegetation: Commonly used for growing cultivated crops. Corn (*Zeamays* L.), soybeans (*Glycine max* (L.) Merr), small grains, and hay are grown. Native vegetation was tall prairie grasses.

Distribution and Extent: Southwestern Iowa, northwestern Missouri, northeastern Kansas, and southeastern Nebraska. The soils are extensive.

Series Established: Lancaster County, Nebraska, 1944.

Remarks: Diagnostic horizons and features recognized in this pedon are: mollic epipedon—the zone from the surface to a depth of 43 cm (Ap, A1, and A2 horizons); argillic horizon—the zone from 43 cm to a depth of 97 cm (Bt1, Bt2, and Bt3 horizons); udic moisture regime.

IA0033 SOIL INTERPRETATIONS RECORD SHARPSBURG SERIES

MLRA(S): 106, 107, 108, 109
REV. LDL. 10-90
TYPIC ARGIUDOLLS, FINE, MONTMORILLONITIC, MESIC

THE SHARPSBURG SERIES CONSISTS OF MODERATELY WELL DRAINED SOILS FORMED IN LOESS UNDER PRAIRIE VEGETATION ON UPLAND DIVIDES AND STREAM BENCHES. THE SURFACE SOIL IS BLACK VERY DARK BROWN AND VERY DARK GREYISH BROWN SILTY CLAY LOAM 17 INCHES THICK. THE SUBSOIL IS BROWN SILTY CLAY LOAM IN UPPER 7 INCHES AND BROWN AND YELLOWISH BROWN MOTTLED SILTY CLAY LOAM IN LOWER 22 INCHES. THE SUBSTRATUM IS MOTTLED GRAYISH BROWN, YELLOWISH BROWN AND STRONG BROWN SILTY CLAY LOAM. SLOPES RANGE FROM 0 TO 18 PERCENT. MOST AREAS ARE USED FOR CROPLAND.

LANDSCAPE AND CLIMATE PROPERTIES

ANNUAL AIR TEMPERATURE	FROST FREE DAYS	ANNUAL PRECIPITATION	ELEVATION (FT)	DRAINAGE CLASS	SLOPE (PCT)
50-57	160-170	28-38	1000-1300	MW	0-18

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT. >10 IN (PCT)	FRACT. 3-10 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	2000	CLAY (PCT)
0-17	SICL	CL, CH	A-7, A-6	0	0	100	100	100	95-100	27-36
0-17	SIL	CL	A-6	0	0	100	100	100	95-100	25-27
17-31	SICL, SIC	CH, CL	A-7	0	0	100	100	100	95-100	36-42
31-46	SICL	CL	A-7,A-6	0	0	100	100	100	95-100	30-38
46-60	SICL, SIL	CL	A-7, A-6	0	0	100	100	100	95-100	25-32

DEPTH (IN.)	LIQUID LIMIT	PLASTICITY INDEX	MOIST BULK DENSITY (G/CM3)	PERMEABILITY (IN/HR)	AVAILABILITY WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALANITY (MMHOS/CM)	SAR	CEC (ME/100G)	CACO3 (PCT)	GYPSUM (PCT)
0-17	35-55	18-32	1.30-1.35	0.6-2.0	0.21-0.23	5 1-7.3	-	-	25-30	-	-
0-17	25-40	10-20	1.30-1.35	0.6-2.0	0.21-0.23	5.1-7.3	-	-	25-30	-	-
17-31	40-60	20-35	1.35-1.40	0.2-0.6	0.18-0.20	5.1-6.0	-	-	25-30	-	-
31-46	35-50	20-30	1.40-1.45	0.6-2.0	0.18-0.20	5.1-6.5	-	-	25-30	-	-
46-60	35-50	20-30	1.40-1.45	0.6-2.0	0.18-0.20	6.1-6.5	-	-	25-30	-	-

DEPTH (IN.)	ORGANIC MATTER (PCT)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WIND EROD. GROUP	WIND EROD. INDEX	CORROSIVITY STEEL	CONCRETE
0-17	3-4	MODERATE	.32	5	7	38	MODERATE	MODERATE
0-17	3-4	MODERATE	.32	5	6	48		
17-31	1-2	MODERATE	.43					
31-46	.5-1	MODERATE	.43					
46-60	0-1	MODERATE	.43					

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPH (IN)	HARDNESS	BEDROCK DEPH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0			-		>60				B	HIGH

SANITARY FACILITIIES

SEPTIC TANK ABSORPTION FIELDS	0-15%: SEVERE-PERCS SLOWLY 15+%: SEVERE-PERCS SLOWLY, SLOPE
SEWAGE LAGOON AREAS	0-2%: MODERATE-SEEPAGE 2-7%: MODERATE-SEEPAGE, SLOPE 7+%: SEVERE-SLOPE
SANITARY LANDFILL (TRENCH)	0-8%: MODERATE-TOO CLAYEY 8-15%: MODERATE-SLOPE, TOO CLAYEY 15+%: SEVERE-SLOPE
SANITARY LANDFILL (AREA)	0-8: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
DAILY COVER FOR LANDFILL	0-8: FAIR-TOO CLAYEY 8-15%. FAIR-TOO CLAYEY, SLOPE 15+%: POOR-SLOPE

BUILDING SITE DEVELOPMENT

SHALLOW EXCAVATIONS	0-8%: MODERATE-TOO CLAYEY 8-15%: MODERATE-TOO CLAYEY, SLOPE 15+%: SEVERE-SLOPE
DWELLINGS WITHOUT BASEMENTS	0-8%: MODERATE-SHRINK-SWELL 8-15%: MODERATE-SHRINK-SWELL, SLOPE 15+%: SEVERE-SLOPE
DWELLINGS WITH BASEMENTS	0-8%. MODERATE-SHRINK-SWELL 8-15%. MODERATE-SLOPE, SHRINK-SWELL 15+%: SEVERE-SLOPE
SMALL COMMERCIAL BUILDINGS	0-4%: MODERATE-SHRINK-SWELL 4-8%: MODERATE-SHRINK-SWELL, SLOPE 8+%: SEVERE-SLOPE
LOCAL ROADS AND STREETS	0-15 SEVERE-LOW STRENGTH, FROST ACTION 15+%: SEVERE-LOW STRENGTH, SLOPE, FROST ACTION
LAWNS LANDSCAPING AND GOLF FAIRWAYS	0-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE

CONSTRUCTION MATERIAL

ROADFILL	POOR-LOW STRENGTH
SAND	IMPROBABLE-EXCESS FINES
GRAVEL	IMPROBABLE-EXCESS FINES
TOPSOIL	0-15%. POOR THIN LAYER 15+%: POOR THIN LAYER, SLOPE

WATER MANAGEMENT

POND RESERVOIR AREA	0-3%. MODERATE-SEEPAGE 3-8%. MODERATE-SEEPAGE, SLOPE 8+%: SEVERE-SLOPE
EMBANKMENTS DIKES AND SLEAVES	SLIGHT
EXCAVATED PONDS AQUIFER FED	SEVERE-NO-WATER
DRAINAGE	DEEP TO WATER
IRRIGATION	0-3%. FAVORABLE 3+% SLOPE
TERRACES AND DIVERSIONS	0-8%: ERRODES EASILY 8+%: SLOPE, ERODES EASILY
GRASSED WATERWAYS	0-8%: ERRODES EASILY 8+%: SLOPE, ERODES EASILY

SHARPSBURG SERIES IA0033

RECREATIONAL DEVELOPMENT

CAMP AREAS	0-8%: MODERATE-PERCS, SLOWLY 8-15+%: MODERATE-SLOPE PERC SLOWLY 15+%: SEVERE-SLOPE	PLAYGROUNDS	0-2%: MOOERATE-PERCS, SLOWLY 2-6%: MOOERATE-SLOPE, PERCS SLOWLY 6+%: SEVERE-SLOPE
PICNIC AREAS	0-8%: MODERATE-PERCS, SLOWLY 8-15+%: MODERATE-SLOPE PERC SLOWLY 15+%: SEVERE-SLOPE	PATHS ANO TRAILS	0-15%: SLIGHT 15-18%: MODERATE-SLOPE

REGIONAL INTERPRETATIONS

CAPABILITY AND YIELDS PER ACRE OF CROPS AND PASTURE (HIGH LEVEL MANAGEMENT)

CLASS-DETERMINING PHASE	CAPABILITY		CORN (BU)		SOYBEANS (BU)		OATS (BU)		BROMEGRASS ALFALFA HAY (TONS)		KENTUCKY BLUEGRASS (AUM)		SMOOTH BRUMEGRASS (AUM)		BRUMEGRASS ALFALFA (AUM)	
	NIRR.	IRR	NIRR.	IRR	NIRR.	IRR.	NIRR.	IRR.	NIRR	IRR.	NIRR.	IRR.	NIRR	IRR.	NIRR	IRR.
0-2%	1		156		52		78		6.6		3.8		6.4		10.9	
2-5%	2E		153		51		77		6.4		3.8		6.3		10.7	
5-9%	3E		148		50		74		6.2		3.6		6.1		10.4	
9-14%	3E		139		47		70		5.8		3.4		5.7		9.8	
14-18%	4E		122		41		61		5.1		3.0		5.0		8.6	

WOODLAND SUITABILITY

CLASS-OETERMINING PHASE	ORD SYM	MANAGEMENT PROBLEMS					POTENTIAL PRODUCTIVITY			TREES TO PLANT
		EROS'N HAZARO	EQUIP. LIMIT	SEEDL. MORT'Y	WINDTH HAZARO	PLANT COMPET	COMMON TREES	SITE INOX	PROD CLAS	
							NONE			

WINDBREAKS (A)

CLASS-DETERMINIG PHASE	SPECIES	H1	SPECIES	H1	SPECIES	H1	SPECIES	H1
HIGH PPT	SILKY DOGWOOD	8	AMUR HONEYSUCKLE	12	AMER CRANBERRYBUSH	10	AMUR PRIVET	15
	EASTERN WHITE PINE	41	PIN OAK	36	AUSTRIAN PINE	28	NORWAY SPRUCE	32
	WHITE FIR	23	BLUE SPRUCE	22	NORTHERN WHITECEDAR	22	WASHINGTON HAWTHORN	18
LOW PPT	AMUR MAPLE	12	GREEN ASH	25	HACKBERRY	24	AMUR HONEYSUCKLE	8
	LILAC	8	AUSTRIAN PINE	26	BUR OAK	24	EASTERN REOCEOAR	22
	AUTUMN OLIVE	12	EASTERN WHITE PINE	27	RUSSIAN OLIVE	22	HONEYLOCUST	26

WILDLIFE HABITAT SUITABILITY

CLASS-DETERMINING PHASE	POTENTIAL FOR HABITAT ELEMENTS								POTENTIAL AS HABITAT FOR:			
	GRAIN & SEED	GRASS & LEGUME	WILO HERB.	HARDWO TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	OPENLD WILDLF	WOODLD WILOLF	WETLAND WILDLF	RANGELD WILOLF
0-5%	GOOO	GOOD	GOOD	GOOD	GOOD	-	POOR	POOR	GOOO	GOOD	POOR	
5-15%	FAIR	GOOD	GOOD	GOOD	GOOD	-	POOR	POOR	GOOD	GOOO	POOR	
15+%	POOR	FAIR	GOOD	FAIR	FAIR	-	POOR	POOR	FAIR	FAIR	POOR	

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION) (B)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS OETERMINING PHASE				
		ALL				
BIG BLUESTEM	ANGE	30				
LITTLE BLUESTEM	SCSC	15				
SIDEOATS GRAMA	BOCU	5				
INDIANGRASS	SONU2	5				
SWITCHGRASS	PAVI2	10				
TALL OROPSEED	SPAS	5				
SEOGE	CAREX	5				
LEADPLANT	AMCA6	5				
KENTUCKY BLUEGRASS	POPR	5				
OTHER PERENNIAL GRASSES	PPGG	5				
OTHER PERENNIAL FORBS	PPFF	5				
OTHER SHRUBS	SSSS	5				
POTENTIAL PRODUCTION (LBS./AC.DRY WT):						
FAVORABLE YEARS		4800				
NORMAL YEARS		4400				
UNFAVORABLE YEARS		4000				

FOOTNOTES

A WINDBREAK GROUP 3, HIGH PPT: LRA 108, 109; LOW PPT: 106, 107

B SILTY RANGE SITE, NEBRASKA

Bakeoven Official Soil Series Description

The Bakeoven series consists of very shallow, well drained soils that formed in mixed alluvium, loess, and residuum weathered from basalt. Bakeoven soils are on uplands and have slopes of 0 to 90 percent. The mean annual precipitation is about 330 mm and the mean annual temperature is about 9 °C.

Taxonomic Class: Loamy-skeletal, mixed, mesic Lithic Haploxerolls

Representative Pedon: Bakeoven very cobbly loam-rangeland. Colors are for dry soil unless otherwise noted.

A—0 to 5 cm; brown (7.5YR 5/3) very cobbly loam, dark brown (7.5YR 3/2) moist; weak thin platy and weak fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine roots; many very fine irregular pores; about 40 percent by volume of rock fragments; slightly acid (pH 6.5); abrupt smooth boundary. (0 to 10 cm thick)

Bw1—5 to 10 cm; brown (7.5YR 5/3) very gravelly heavy loam, dark brown (7.5YR 3/3) moist; weak thin platy and weak fine and medium granular structure; slightly hard, friable, sticky and plastic; common very fine roots; common very fine irregular pores; about 60 percent by volume of rock fragments; neutral (pH 6.8); abrupt smooth boundary. (5 to 15 cm thick)

Bw2—10 to 18 cm; brown (10YR 5/3) very gravelly clay loam, dark brown (10YR 3/3) moist; moderate fine subangular blocky structure; hard, friable, sticky and plastic; common very fine roots; common very fine tubular pores; about 60 percent by volume of rock fragments; neutral (pH 6.9); abrupt wavy boundary. (2 to 10 cm thick)

2R—18 cm; basalt.

Type Location: Wasco County, Oregon; 360 m south and 30 m east of center of sec. 7; NW1/4, SE1/4 sec. 7. T. 8 S., R. 15 E.

Range in Characteristics: The soil is dry throughout above the lithic contact for more than half the time (cumulative) that the soil temperature is above 5 °C. The mean annual soil temperature ranges from 8 to 12 °C. Thickness of solum and depth to bedrock range from about 10 to

25 cm. Rock fragments commonly range from 50 to 90 percent, but the upper 5 to 10 cm of the deeper sola have as little as 35 percent. Organic matter ranges from 1 to 2 percent. The deeper part of some sola have coatings of carbonates on the underside of rock fragments and these coatings extend in cracks into the underlying rock. The sola have 10YR, 7.5YR, or 5YR hue.

The A horizon has value of 4 or 5 dry, 2 or 3 moist and chroma of 2 or 3 moist and 2 through 4 dry. It is slightly acid to mildly alkaline.

The B horizon has the same color value as that of the A horizon and chroma is 2 or 3 in the upper part and 3 or 4 below depths of 15 or 18 cm in sola thicker than 18 cm. It is loam, clay loam or silt loam and averages more than 18 percent clay and has more than 35 percent rock fragments. This horizon has moderate fine subangular blocky through weak medium subangular blocky structure. It is slightly acid to mildly alkaline.

Clay films are present on some rock fragments in deeper sola or in the fractures in the underlying bedrock.

Competing Series: These are the Aldax, Bodell, Couleedam, Johntom, Lickskillet, Limekiln, Plaskett, and Venator series. All of these soils are deeper than 25 cm to bedrock. Aldax and Plaskett soils have less than 18 percent clay in the particle-size control section. Limekiln soils have a calcic horizon. Plaskett soils have mean annual soil temperature of 13 to 15 °C.

Geographic Setting: The Bakeoven soils are on ridge tops, hillslopes and benches at elevations of 180 to 1600 meters. Slopes of 2 to 20 percent are most common and the full range is from about 0 to 90 percent. The soils formed in loess and residuum weathered from basalt. The climate is semiarid. The mean annual precipitation ranges from 25 to 40 cm, the mean annual temperature is from 7 to 11 °C, the mean winter temperature is from 7 to 11 °C, and the mean summer temperature is from 17 to 19 °C. The frost-free period is 100 to 165 days.

Geographically Associated Soils: These are the competing Lickskillet soils and the Anderly, Agency, Cantala, Condon, Gem, Maupin, Morrow, Reywat, Ritzville, Ruckles, Starbuck, Walla Walla, Wapinitia, Watama and Wrentham soils. Agency soils are moderately deep to bedrock and have less than 35 percent rock fragments. Anderly and Condon soils are moderately deep and formed in loess over bedrock and in many places are "biscuits" associated with Bakeoven soils. Cantala soils are fine-silty and deeper than 1 m to bedrock. Gem and Morrow soil have an argillic horizon and are moderately deep to

bedrock. Maupin soils have a duripan and are fine-loamy. Reywat soils are shallow and have a skeletal argillic horizon. Ritzville and Walla Walla soils are deep or very deep, formed in loess, and are free of rock fragments. Ruckles soils have a very stony argillic horizon. Starbuck soils are on steep south-facing slopes, lack a mollic epipedon, formed mostly in loess, and contain less than 35 percent rock fragments. Wapinitia soils are deep and have an argillic horizon. Watama soils are moderately deep and are fine-loamy. Wrentham soils are on steep north-facing slopes and are deeper than 50 cm to bedrock.

Drainage and Permeability: Well drained; medium runoff (Soil Survey Staff, 1951); moderately slow permeability and in the moderately high saturated hydraulic conductivity class. In a few places, the soil is ponded for short periods.

Use and Vegetation: Most of the soil is used for range. Native vegetation is bunchgrasses, forbs, and shrubs.

Distribution and Extent: North-central Oregon, eastern Washington, and southwestern Idaho. This series is extensive.

Series Established: Sherman County, Oregon; 1962.

OR0011 SOIL INTERPRETATIONS RECORD BAKEOVEN SERIES

MLRA(S): 8, 10
REV, GLG, MD, 6-90
LITHIC HAPLEXEROLLS, LOAMY-SKELETAL, MIXED, MESIC

THE BAKEOVEN SERIES CONSISTS OF WELL DRAINED SOILS FORMED IN LOESS MIXED WITH COLLUVIUM ON RIDGETOPS AND PLATEAUS. TYPICALLY, THE SURFACE LAYER IS VERY COBBLY LOAM ABOUT 8 INCHES THICK. THE SUBSOIL IS VERY GRAVELLY LOAM AND CLAY LOAM ABOUT 5 INCHES THICK OVER BASALT.

LANDSCAPE AND CLIMATE PROPERTIES

ANNUAL AIR TEMPERATURE	FROST FREE DAYS	ANNUAL PRECIPITATION	ELEVATION (FT)	DRAINAGE CLASS	SLOPE (PCT)
45-52	100-165	10-16	540-4300	W	0-90

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT. >10 IN (PCT)	FRACT. 3-10 IN PCT	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	2000	CLAY (PCT)
0-2	STV-L STV-SIL	GM, SM	A-4	15-25	10-20	65-80	60-75	50-70	35-50	15-25
0-2	CBV-L CBV-SIL	GM	A-2, A-4	10-20	25-40	50-70	40-65	35-50	30-50	15-25
0-2	STX-SIL, STX-L	GM, SM	A-4	25-40	20-30	65-80	60-75	50-70	35-50	15-25
2-7	GRV-CL, CBV-L, GRV-L	GM, GC	A-4, A-6	5-15	15-40	50-65	45-60	45-55	35-50	18-33
7	UWB									

DEPTH (IN.)	LIQUID LIMIT	PLAS-TICITY INDEX	MOIST BULK DENSITY (G/CM3)	PERMEA-BILITY (IN/HR)	AVAILABILITY WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALANITY (MMHOS/CM)	SAR	CEC (ME/100G)	CACO3 (PCT)	GYPSUM (PCT)
0-2	25-35	NP-10	1.25-1.35	0.2-0.6	0.06-0.14	6.1-7.8	-	-	10-25	-	-
0-2	25-35	NP-10	1.25-1.35	0.2-0.6	0.06-0.09	6.1-7.8	-	-	10-25	-	-
0-2	25-35	NP-10	1.25-1.35	0.2-0.6	0.06-0.09	6.1-7.8	-	-	10-25	-	-
2-7	30-40	5-15	1.30-1.40	0.2-0.6	0.05-0.14	6.6-7.8	-	-	10-30	-	-
7											

DEPTH (IN.)	ORGANIC MATTER (PCT)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WIND EROD. GROUP	WIND EROD. INDEX	CORROSIVITY STEEL	CONCRETE
0-2	1-3	LOW	.15	1	8	-	MODERATE	LOW
0-2	1-3	LOW	.15	1	8	-		
0-2	1-3	LOW	.10	1	8	-		
2-7	.5-2	LOW	.20					
7								

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH FT	KIND	MONTHS	CEMENTED PAN DEPH (IN)	HARDNESS	BEDROCK DEPH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0			-		4-12	HARD	-		D	MODERATE

SANITARY FACILITIES

SEPTIC TANK ABSORPTION FIELDS	0-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK, SLOPE
SEWAGE LAGOON AREAS	0-7% STV: SEVERE-DEPTH TO ROCK 7% STV: SEVERE-DEPTH TO ROCK, SLOPE 0-7+% CBV, STX: SEVERE-DEPTH TO ROCK, LARGE STONES 7+% CBV, STX:SEVERE-DEPTH TO ROCK, SLOPE
SANITARY LANDFILL (TRENCH)	0-15% STV: SEVERE-DEPTH TO ROCK 15+% STV: SEVERE-DEPTH TO ROCK, SLOPE 0-15% CBV, STX: SEVERE-DEPTH TO ROCK, LARGE STONES 15+% CBV, STX:SEVERE-DEPTH TO ROCK, SLOPE
SANITARY LANDFILL (AREA)	0-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK, SLOPE
DAILY COVER FOR LANDFILL	0-15%: POOR-DEPTH TO ROCK 15+%: POOR-DEPTH TO ROCK, SLOPE

BUILDING SITE DEVELOPMENT

SHALLOW EXCAVATIONS	0-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK, SLOPE
DWELLINGS WITHOUT BASEMENTS	0-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK, SLOPE
DWELLINGS WITHOUT BASEMENTS	0-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK, SLOPE
SMALL COMMERCIAL BUILDINGS	0-8%: SEVERE-DEPTH TO ROCK 8+%: SEVERE-SLOPE, DEPTH TO ROCK
LOCAL ROADS AND STREETS	0-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-SLOPE, DEPTH TO ROCK,
LAWNS LANDSCAPING AND GOLF FAIRWAYS	STV, STX: SEVERE-DEPTH TO ROCK CBV: SEVERE - SMALL STONES, LARGE STONES, DEPTH TO ROCK

CONSTRUCTION MATERIAL

ROADFILL	0-25%: POOR-DEPTH TO ROCK 25+%: POOR-DEPTH TO ROCK, SLOPE
SAND	IMPROBABLE-EXCESS FINES
GRAVEL	IMPROBABLE-EXCESS FINES
TOPSOIL	0-15%: SEVERE-DEPTH TO ROCK SMALL STONES 15+%: POOR-DEPTH TO ROCK, SMALL STONES, SLOPE

WATER MANAGEMENT

POND RESERVOIR AREA	0-8%: SEVERE-DEPTH TO ROCK 8+%: SEVERE-DEPTH TO ROCK, SLOPE
EMBANKMENTS DIKES AND LEVEES	STV, MODERATE-LARGE STONES CBV, STX: SEVERE-LARGE STONES
EXCAVATED PONDS AQUIFER FED	SEVERE-NO-WATER
DRAINAGE	DEEP TO WATER
IRRIGATION	0-3%: LARGE STONES, DROGHTY 3+%: SLOPE, LARGE STONES, DROGHTY
TERRACES AND DIVERSIONS	0-8%: LARGE STONES, DEPTH TO ROCK 8+%: SLOPE, LARGE STONES, DEPTH TO ROCK
GRASSED WATERWAYS	0-8%: LARGE STONES, DROGHTY 8+%: LARGE STONES, SLOPE, DROGHTY

BAKEOVEN SERIES — RECREATIONAL OEVELOPMENT — 0R0011

CAMP AREAS	0-15% STV SEVERE-OEPTH TO ROCK 15+% STV SEVERE-SLOPE, DEPTH TO ROCK 0-15% CBV STX SEVERE-LARGE STONES, DEPTH TO ROCK, 15+% CBV, STX SEVERE-SLOPE, LARGE STONES	PLAYGROUNOS	0-6% SEVERE-LARGE STONES, SMALL STONES 6+% SEVERE-LARGE STONES, SLOPE, SMALL STONES
PICNIC AREAS	0-15% STV SEVERE-DEPTH TO ROCK 15+% STV SEVERE-SLOPE, OEPTH TO ROCK 0-15% CBV, STX SEVERE-LARGE STONES, OEPTH TO ROCK 15+% CBV, STX SEVERE-SLOPE, LARGE STONES	PATHS ANO TRAILS	0-15% STV MOOERATE OUSTY 15-25% STV, MODERATE-SLOPE, DUSTY 0-15% CBV, STX MOOERATE-LARGE STONES, OUSTY 15-25% CBV, STX MOOERATE-LARGE STONES, SLOPE 25+% SEVERE-SLOPE

REGIONAL INTERPRETATIONS

CAPABILITY ANO YIELOS PER ACRE OF CROPS ANO PASTURE (HIGH LEVEL MANAGEMENT)

CLASS-OETERMINING PHASE	CAPABILITY															
	NIRR	IRR	NIRR	IRR	NIRR	IRR	NIRR	IRR	NIRR	IRR	NIRR	IRR	NIRR	IRR	NIRR	IRR
ALL	7S															

WOOOLANO SUITABILITY

CLASS-OETERMINING PHASE	ORD SYM	MANAGEMENT PROBLEMS					POTENTIAL PROOUCTIVITY			TREES TO PLANT
		EROS'N HAZARO	EOUIP LIMIT	SEEOL MORT'Y	WINDTH HAZARO	PLANT COMPET	COMMON TREES	SITE INOX	PROD CLAS	
							NONE			

WINOBREAKS (A)

CLASS-DETERMINIG PHASE	SPECIES	H1	SPECIES	H1	SPECIES	H1	SPECIES	H1
	NONE							

WILOLIFE HABITAT SUITABILITY

CLASS-OETERMINING PHASE	POTENTIAL FOR HABITAT ELEMENTS								POTENTIAL AS HABITAT FOR			
	GRAIN & SEEO	GRASS & LEGUME	WILO HERB.	HAROWO TREES	CONIFER PLANTS	SHRUBS	WETLANO PLANTS	SHALLOW WATER	OPENLO WILOLF	WOOOLO WILOLF	WETLANO WILOLF	RANGELO WILOLF
ALL	V POOR	V POOR	FAIR	-	-	FAIR	V POOR	V POOR	V POOR	-	V POOR	FAIR

POTENTIAL NATIVE PLANT COMMUNITY (RANGELANO OR FOREST UNOERSTORY VEGETATION) (A)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS OETERMINING PHASE				
		0-90%	ORY			
SANOBERG BLUEGRASS	POSE	50	35			
STIFF SAGEBRUSH	ARRI2	10	35			
OTHER PERENNIAL GRASSES	PPGG	5	-			
BUCKWHEAT	ERIOG	2	10			
BLUEBUNCH WHEATGRASS	AGSP	5	5			
PHLOX	PHLOX	2	5			
OTHER PERENNIAL FORBS	PPFF	-	10			
POTENTIAL PROOUCTION (LBS /AC.DRY WT)						
FAVORABLE YEARS		350	200			
NORMAL YEARS		300	125			
UNFAVORABLE YEARS		200	75			

FOOTNOTES

A 0-90% VERY SHALLOW 9-15PZ, ORY 010XY002I

Condon Official Soil Series Description

The Condon series consists of moderately deep, well drained soils that formed in loess overlying basalt. Condon soils are on uplands and have slopes of 0 to 40 percent. Mean annual precipitation is about 300 mm and the mean annual temperature is about 9 °C.

Taxonomic Class: Fine-silty, mixed, mesic Typic Haploxerolls

Representative Pedon: Condon silt loam-cultivated. Colors are for dry soil unless otherwise noted.

Ap—0 to 18 cm; grayish brown (10YR 5/2) silt loam, very dark brown (10YR 2/2) moist; weak medium platy and weak medium granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common fine irregular pores; neutral (pH 6.6); abrupt smooth boundary. (15 to 25 cm thick)

Bw1—18 to 36 cm; grayish brown (10YR 5/2) silt loam, very dark grayish brown (10YR 3/2) moist; weak medium to coarse prismatic and weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tubular pores; neutral (pH 6.7); clear smooth boundary. (10 to 30 cm thick)

Bw2—36 to 50 cm; brown (10YR 5/3) silt loam, dark brown (10YR 3/3) moist; weak medium to coarse prismatic and weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tubular pores; neutral (pH 6.8); clear wavy boundary. (10 to 30 cm thick)

BC—50 to 70 cm; pale brown (10YR 6/3) silt loam, dark brown (10YR 4/3) moist; weak coarse prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tubular pores; neutral (pH 7.0); abrupt wavy boundary. (0 to 50 cm thick)

2R—79 cm; basalt.

Type Location: Gilliam County, Oregon; 1.3 km west of Condon city limits; 53 m west of fence, 45 m north of Condon-Moro road in the SE1/4, SW1/4, NW1/4 sec. 9. T. 4 S., R. 21 E.

Range in Characteristics: The soils are usually moist but are dry for 80 to 90 consecutive days between depths of 10 and 30 cm following the summer solstice. The mean annual soil temperature ranges from 8 to

12 °C. Thickness of the solum and depth to bedrock range from 50 to 100 cm. Organic matter decreases to less than 1 percent at depths of less than 50 cm and commonly between 25 and 38 cm.

The A horizon has value of 4 or 5 dry, 2 or 3 moist and chroma of 2 or 3 moist and dry. It is slightly acid or neutral.

The B horizon has value of 3 or 4 moist, 5 or 6 dry, but 3 moist and 5 dry above 25 cm and chroma of 2 thru 4 moist and dry. It is silt loam and averages 18 to 27 percent clay and less than 15 percent coarser than very fine sand. This horizon has weak to moderate structure. It is slightly acid through slightly alkaline.

Competing Series: These are the Cantala and Couse series. Cantala and Couse soils are deeper than 100 cm to bedrock.

Geographic Setting: Condon soils are on uplands at elevations of 330 to 1200 meters. Slopes are 0 to 40 percent. These soils formed in a loess mantle with an appreciable component of volcanic ash overlying basalt. Summers are warm and dry and winters are cool and moist. Mean summer temperature is 16 to 18 °C, and mean winter temperature is 0 to 1 °C. Mean annual temperature is 7 to 9 °C. Precipitation ranges from 250 to 380 mm. The frost-free period is 100 to 165 days.

Geographically Associated Soils: These are the Bakeoven, Lickskillet, Valby, and Wrentham soils and the competing Cantala soils. All of these except Valby and Cantala soils contain more than 35 percent rock fragments. Also, Bakeoven and Lickskillet soils are less than 50 cm deep to bedrock. Valby soils are calcareous at depths of 38 to 76 cm.

Drainage and Permeability: Well drained; slow to rapid runoff; moderate permeability.

Use and Vegetation: Principal use is for growing grain crops. Other uses are production of hay, pasture, and native range. Native plants are bluebunch wheatgrass (*Agropyron spicatum* (Scrib and J.G. Smith) A. Heller), Idaho fescue (*Festuca idahonsis* Elmer), Sandberg bluegrass (*Poa secunda* J. Presl.), and forbs such as yarrow (*Achillea* L.), phlox (*Phlox* L.), and buckwheat (*Eriogonum* Michx.).

Distribution and Extent: North-central Oregon and south-central Washington. The series is extensive.

Series Established: Rock Creek Project, Gilliam County, Oregon, 1939.

Additional Data: Characterization data on 3 profiles (S57-OR-065-19, S89OR-065-001, S89OR-065-002).

Series Revision Date—1/90

OR0021 S O I L I N T E R P R E T A T I O N S R E C O R O CONDON SERIES

MLRA(S): 8
REV, GLG, MSA, 12-89
TYPIC HAPLOXEROLLS, FINE-SILTY, MIXEO, MESIC

THE CONOON SERIES CONSISTS OF MOOERATELY OEEP SOILS FORMEO IN AEOLIAN MATERIALS ON RIDGETOPS AND HILLSLOPES TYPICALLY, THE SURFACE LAYERS IS SILT LOAM ABOUT 7 INCHES THICK THE SUBSOILS IS SILT LOAM ABOUT 24 INCHES THICK OVER BEOROCK

LANOSCAPE ANO CLIMATE PROPERTIES

ANNUAL AIR TEMPERATURE	FROST FREE OAYS	ANNUAL PRECIPITATION	ELEVATION (FT)	ORAINAGE CLASS	SLOPE (PCT)
45-52	100-165	10-15	1100-4000	W	0-40

ESTIMATEO SOIL PROPERTIES

OEPTH (IN.)	USOA TEXTURE	UNIFIEO	AASHTO	FRACT. >10 IN (PCT)	FRACT. 3-10 IN PCT	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO 4	10	40	200	CLAY (PCT)
0-7	SIL	ML, CL-ML	A-4	0	0	100	95-100	95-100	80-90	15-25
7-31	SIL	CL, CL-ML	A-4, A-6	0	0	100	100	95-100	80-90	18-27
31	UWB									

OEPTH (IN.)	LIQUIO LIMIT	PLAS-TICITY INOEX	MOIST BULK OENSITY (G/CM3)	PERMEA-BILITY (IN/HR)	AVAILABILITY WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALANITY (MMHOS/CM)	SAR	CEC (ME/100G)	CACO3 (PCT)	GYPSUM (PCT)
0-7	25-33	5-10	1.25-1.35	0.6-2.0	0.20-0.25	6 1-7.3	-	-	10-20	-	-
7-31	25-33	5-15	1.30-1.40	0 6-2.0	0.19-0.21	6.1-7.8	-	-	10-20	-	-
31											

OEPTH (IN)	ORGANIC MATTER (PCT)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WINO EROD. GROUP	WINO EROD. INOEX	CORROSIVITY STEEL	CONCRETE
0-7	2-3	LOW	43	2	5	56	MOOERATE	LOW
7-31	.5-2	LOW	43					
31								

FLOOOING FREOUENCY	OURATION	MONTHS	HIGH WATER TABLE OEPTH FT	KINO	MONTHS	CEMENTEO PAN OEPH (IN)	HARDNESS	BEOROCK DEPH (IN)	HARONESS	SUBSIOENCE INIT. (IN)	TOTAL (IN)	HYO GRP	POTENT'L FROST ACTION
NONE			>6.0			-		20-40	HARO	-		C	HIGH

SANITARY FACILITIES

SEPTIC TANK ABSORPTION FIELOS	0-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-OEPTH TO ROCK, SLOPE
SEWAGE LAGOON AREAS	0-7%: SEVERE-OEPTH TO ROCK 7%: SEVERE-OEPTH TO ROCK, SLOPE
SANITARY LANOFILL (TRENCH)	0-15% STV: SEVERE-OEPTH TO ROCK 15+% STV SEVERE-OEPTH TO ROCK, SLOPE
SANITARY LANOFILL (AREA)	0-15%: SEVERE-OEPTH TO ROCK 15+%: SEVERE-OEPTH TO ROCK, SLOPE
OAILY COVER FOR LANOFILL	0-15%: POOR-OEPTH TO ROCK 15+%: POOR-OEPTH TO ROCK, SLOPE

BUILOING SITE OEVELOPMENT

SHALLOW EXCAVATIONS	0-15%: SEVERE-OEPTH TO ROCK 15+%: SEVERE-OEPTH TO ROCK, SLOPE
OWELLINGS WITHOUT BASEMENTS	0-8%: MOOERATE-OEPTH TO ROCK 8-15%: MOOERATE-OEPTH TO ROCK, OEPTH TO ROCK 15+%: SEVERE-SLOPE
OWELLINGS WITHOUT BASEMENTS	0-15%: SEVERE-OEPTH TO ROCK 15+%: SEVERE-OEPTH TO ROCK, SLOPE
SMALL COMMERCIAL BUILOINGS	0-4%: MOOERATE-OEPTH TO ROCK 4-8%: MOOERATE-SLOPE, OEPTH TO ROCK 8+%: SEVERE-SLOPE
LOCAL ROAOS ANO STREETS	0-15%: SEVERE-FROST ACTION 15+%: SEVERE-SLOPE, FROST ACTION
LAWNS LANOSCAPING ANO GOLF FAIRWAYS	0-8%: MOOERATE-OEPTH TO ROCK 8-15%: MOOERATE-SLOPE, OEPTH TO ROCK 15+%: SEVERE-SLOPE

CONSTRUCTION MATERIAL

ROAOFILL	0-25%: POOR-OEPTH TO ROCK 25+%: POOR-OEPTH TO ROCK, SLOPE
SANO	IMPROBABLE-EXCESS FINES
GRAVEL	IMPROBABLE-EXCESS FINES
TOPSOIL	0-8%: FAIR-OEPTH TO ROCK, THIN LAYER 8-15+%: FAIR-OEPTH TO ROCK, THIN LAYER, SLOPE 15+%: POOR-SLOPE

WATER MANAGEMENT

PONO RESERVOIR AREA	0-3%: SEVERE-OEPTH TO ROCK 3-8%: SEVERE-OEPTH TO ROCK, SLOPE 8+%: SEVERE-SLOPE
EMBANKMENTS OIKES ANO LEVEES	SEVERE-PIPING
EXCAVATEO PONOS AOUIFER FEO	SEVERE-NO WATER
ORAINAGE	OEEP TO WATER
IRRIGATION	0-3%: OEPTH TO ROCK, EROOES EASILY 3+%: SLOPE, OEPTH TO ROCK, EROOES EASILY
TERRACES ANO OIVERSIONS	0-8%: OEPTH TO ROCK, EROOES EASILY 8+%: SLOPE, OEPTH TO ROCK, EROOES EASILY
GRASSEO WATERWAYS	0-8%: EROOES EASILY, OEPTH TO ROCK 8+%: SLOPE, EROOES EASILY, OEPTH TO ROCK

CONOON SERIES — RECREATIONAL OEVELOPMENT — OR0021

CAMP AREAS	0-8%: MODERATE-DUSTY 8-15%: MODERATE-SLOPE, DUSTY 15+%: SEVERE-SLOPE	PLAYGROUNDS	0-2%: MODERATE-OUSTY 2-6%: MODERATE-SLOPE, DEPTH TO ROCK, OUSTY 6+%: SEVERE-SLOPE
PICNIC AREAS	0-8%: MODERATE-DUSTY 8-15%: MODERATE-SLOPE, DUSTY 15+%: SEVERE-SLOPE	PATHS AND TRAILS	0-25%: SEVERE-ERODES EASILY 25+%: SEVERE-SLOPE, ERODES EASILY

REGIONAL INTERPRETATIONS

CAPABILITY AND YIELOS PER ACRE OF CROPS ANO PASTURE (HIGH LEVEL MANAGEMENT)

CLASS-DETERMINING PHASE	CAPABILITY															
	NIRR.	IRR.	NIRR.	IRR.	NIRR.	IRR.	NIRR.	IRR.	NIRR.	IRR.	NIRR.	IRR.	NIRR.	IRR.	NIRR.	IRR.
0-7%	3S	3E	30		0.75		3		35							
7-12% NORTH	3E	3E	30		0.75		3		35							
12-20% NORTH	3E		30		0.75		3		35							
7-35% SOUTH	4E		15				2		30							
20-35% NORTH	4E		30		0.75		3		35							

WOOOLANO SUITABILITY

CLASS-DETERMINING PHASE	ORD SYM	MANAGEMENT PROBLEMS					POTENTIAL PRODUCTIVITY			TREES TO PLANT
		ERDS'N HAZARD	EQUIP. LIMIT	SEEDL. MORT'Y	WINDTH HAZARD	PLANT COMPET	COMMON TREES	SITE INDX	PROD CLAS	
							NDNE			

WINDBREAKS (A)

CLASS-OETERMINIG PHASE	SPECIES	H1	SPECIES	H1	SPECIES	H1	SPECIES	H1
IRR	PEKING COTONEASTER	8	SKUNK BUSH SUMAC	15	AUSTRIAN PINE	35	SIBERIAN ELM	35
	REOOSIER OOGWOOO	8	ROCKY MT. JUNIPER	25	SCOTCH PINE	35	HONEYSUCKLE	15
	SIBERIAN PEASHRUB	15	BLUE SPRUCE	25	NORWAY SPRUCE	35	PONDEROSA PINE	35
	LILAC	15	EASTERN REDCEDAR	25	GREEN ASH	35	BLACK LOCUST	35
	NANKING CHERRY	15						

WILDLIFE HABITAT SUITABILITY

CLASS-DETERMINING PHASE	POTENTIAL FOR HABITAT ELEMENTS								POTENTIAL AS HABITAT FOR:			
	GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
ALL	FAIR	GOOO	GOOO	-	-	V. POOR	V. POOR	V. POOR	FAIR	-	V. POOR	V. POOR

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION) (A)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE				
		0-12%	NORTH	SOUTH		
BLUEBUNCH WHEATGRASS	AGSP	50	15	70		
IDAHO FESCUE	FEID	30	70	5		
SANOBERG BLUEGRASS	PDSE	10	3	10		
POTENTIAL PRODUCTION (LBS./AC.DRY WT):						
FAVORABLE YEARS		1400	1400	1200		
NORMAL YEARS		1100	1100	1000		
UNFAVORABLE YEARS		600	700	400		

FOOTNOTES

A ESTIMATES DF ENGINEERING PROPERTIES BASED ON TEST DATA OF TWO PEDONS FROM WASCO COUNTY
B 0-12%, LOAMY 12-14PZ; NORTH, NDRTH 12-14PZ; SOUTH, SOUTH 11-17PZ.

APPENDIX 2 Illustrative map units

Three map units from published soil surveys are in this appendix. They illustrate three kinds of map units: A single soil series (consociation), two soil series as a complex, and a single taxa above the soil series. These are defined in Chapter 2. The information has been somewhat reorganized and rephrased. A small amount of additional information has been added, particularly in respect to the climate. Field work for the three soil surveys was completed in the late 1970's, and the reports were published in the early 1980's. Tabular information is given for the map units for which the named soils are soil series (tables A-1 through A-7). It is not the usual practice to provide tabular information for named soils that are not soil series; therefore, "Lithic Haplargids" lacks tabular information. The tabular information for environmental plantings, recreational development, and wildlife habitat has not been included. Yield information appears in the text. The discussion of interpretive properties and their class limits is mainly in chapter 3 or 6 or given directly.

Single Soil Series (or Consociation)

"Sharpsburg silty clay loam, 5 to 9 percent slopes" illustrates a map unit in a single soil series. The information comes from the soil survey of Lancaster County, Nebraska (Brown et al., 1980), which is located in the southeastern part of the State. Sharpsburg soils are classified as fine, montmorillonitic, mesic Typic Argiudolls. The map scale is 1:15,840. The mean annual precipitation is 750 mm, the potential evaporation by the Thornthwaite method is about 700 mm, the mean annual air temperature is 11°C, and the frost-free period (6 years in 10) is 170 to 180 days. About two-thirds of the county is in cropland.

Parent materials, landscape, and soil occurrence: Sharpsburg soils are developed in deep loess over till. In this map unit they occur on side

slopes in irregular areas that are 1 to 250 hectares in size. An Aquic Argiudoll (Wymore series), developed in loess, occurs near drainageways on lower side slopes; these are the most extensive of the included soils. They have higher clay content in the subsoil than Sharpsburg soils. An Aquic Argiudoll in a fine family (Pawnee series) and a Typic Argiudoll in a fine-loamy family (Morrill series) are formed in glacial till on the steeper side slopes. A fine-silty Cumulic Hapludoll (Judson series) occurs in the colluvium at the base of the slopes. A fine-silty Mollic Udifluvent (Nodaway series) and a Cumulic Haplaquoll (Colo series) are formed in the alluvium.

Generalized soil description: Typically the surface layer of this Sharpsburg soil is very dark brown (moist), friable silty clay loam about 18 cm in thickness. The subsoil is dark brown, friable silty clay loam about 75 cm in thickness and the underlying material to 1.5 m is dark yellowish brown silty clay loam with grayish brown redoximorphic features.

Water-related information: Saturated hydraulic conductivity is moderately high. The available water capacity to 1.5 m is high (23 to 29 cm). Runoff is medium (Soil Survey Staff, 1951). Internal free water occurrence is very deep. Seasonally free water may occur at the top of the underlying glacial till where it can move laterally if the till is relatively shallow.

Agronomic information: This Sharpsburg soil is in land capability subclass IIIe. Organic matter content is moderate (2 to 4 percent in tillage zone) and natural fertility is high. The reaction of the surface layer ranges from strongly acid to slightly acid. The soil is well suited to grain sorghum (*Sorghum bicolor* L. Moench), soybeans (*Glycine May* L. Moench), winter wheat (*Triticum x aestivum* L.), and alfalfa (*Medicago Safiva* L.). Although corn (*Zea mays* L.) for grain is subject to drought damage, it is commonly grown. Yields in 1985 were:

Grain sorghum	5.3 t ha^{-1}
Soybeans	2.0 t ha^{-1}
Wheat	2.5 t ha^{-1}
Alfalfa	9 t ha^{-1}

The cropping system should limit the years of consecutive row crops and should include small grain and alfalfa to help control erosion and conserve water. Under intensive management, more years of row crops can be included. Water erosion control is a major concern. Terraces, grassed waterways, and the use of crop residue help to control erosion.

The soil is well suited to grass. Introduced grasses, such as bromegrass (*Bromus* L.), can be used in the rotation. Native range grasses can be grazed in July and August when introduced grasses are semidormant. The range site is Silty which encompasses deep soils with silty clay loam to very fine sandy loam surface horizons that occur on nearly level to steep slopes. The average dry matter production is 4.4 t ha^{-1}. Big bluestem (*Andropogon gerardii* vitman), little bluestem (*Schizchyrium scoparium* (*Michx.*) Nash), and switchgrass (*Panicum virgatum* L.) together account for 55 percent of the vegetation of the native range.

Nonagricultural information: Water perched on the glacial till is a hazard for buildings with basements. Artificial drainage, footing drains, and basement sump pumps can reduce or overcome seepage. Drainage outlets are generally available. Foundations should be designed to withstand the shrinking and swelling of the soil. Exposed subsoil and underlying material are lower in organic matter and fertility than the surface layer. The surface layer of the soil should be stockpiled and spread over lawn areas when construction and landscaping are completed. This soil has several limitations for septic tank absorption fields (table A1). The soil is not suited for sewage lagoons unless slope is modified. Roads should be placed on the contour to reduce the hazard of erosion.

Complex of Two Soil Series

"Bakeoven-Condon complex, 2 to 20 percent slopes," from the Soil Survey of Wasco County, Oregon, Northern Part (Green, 1982), illustrates a complex of two soil series. The soil survey area is in the north-central part of the State. Bakeoven soils are classified loamy-skeletal, mixed, mesic Lithic Haploxerolls. Condon soils are classified fine-silty, mixed, mesic Typic Haploxerolls. The map scale is 1:20,000. In the mapped area, the mean annual precipitation is 250 to 350 mm, the Thornthwaite potential evapotranspiration is about 650 mm, the mean annual air temperature is 7 to 11 °C, and the frost-free period is 100 to 150 days. The soil survey area is about 75 percent rangeland and is used mainly for cattle-grazing. The remainder is divided about equally between forest land and cropland. Soft white winter wheat under summer fallow is the principal crop.

Parent materials, landscape, and soil occurrence: The map unit is applied to a large area of patterned ground referred to as "biscuit scabland." The parent material is thin loess, and the underlying residuum is from basalt. The Lithic Haploxeroll, Bakeoven, occurs on ridgetops or

side slopes; the Typic Haploxeroll, Condon, occurs on ridgetops or side slopes of circular or elongated mounds. Bakeoven occupies 50 to 85 percent of the area; Condon, 10 to 35 percent. Both occur over the same slope range. A Lithic Haploxeroll with a very stony surface horizon (Lickskillet series) is present in areas between the mounds, as well as unnamed shallow stony soils. In aggregate, these included soils make up to 15 percent of the map unit.

Generalized description: The Lithic Haploxeroll, Bakeoven, has a surface horizon of dark brown (moist) very cobbly loam about 8 cm thick. The subsoil is dark brown very cobbly loam and clay loam about 15 cm thick. Basalt bedrock is at a depth of about 20 cm. The Typic Haploxeroll, Condon, has a surface layer of very dark brown (moist) silt loam about 35 cm thick. The subsoil is mostly dark brown silt loam about 35 cm thick. Basalt bedrock is at a depth of about 70 cm.

Water-related information: The Lithic Haploxeroll (Bakeoven) has moderately high saturated hydraulic conductivity. Available water capacity is 1 to 3 cm to the base of potential rooting. The Typic Haploxeroll (Condon) has a moderately high saturated hydraulic conductivity. Available water capacity is 14 to 17 cm to the base of potential rooting. Runoff for the map unit overall is slow to rapid (Soil Survey Staff, 1951).

Agronomic information: The land capability subclass is VIIs. Effective rooting depth is 13 to 30 cm for the Lithic Haploxeroll (Bakeoven) and 50 to 100 cm for the Typic Haploxeroll (Condon). The Lithic Haploxeroll (Bakeoven) is in a Scabland range site and the Typic Haploxeroll (Condon), is in a Rolling Hills range site. The Scabland range site is restricted to Bakeoven soils. The Rolling Hills range site encompasses well-drained silt loams and very fine sandy loams that are formed in mostly loess and volcanic ash on broad ridgetops and rolling uplands. The Scabland range site produces about 0.4 t ha^{-1} of dry weight under normal conditions. Stiff sagebrush (*Artemisia rigida* (Nutt.) Gray) and Sandburg bluegrass (Sandburg bluegrass *Poa secunda* J. Presl.) account for 95 percent of the vegetation. The Rolling Hills range site produces 0.9 t ha^{-1} of dry weight under normal conditions. Bluebunch wheatgrass (*Agropyron spicatum* (Scrubn. and J.G. Smith) A. Heller) and Idaho fescue (*Festuca idahoensis* Elmer) account for 85 percent of the vegetation.

Nonagricultural information: These soils are limited in their use for building sites, water management, and waste disposal systems because of the shallow depth to bedrock.

Taxa Above the Soil Series

"Lithic Haplargids, moderately sloping" is a map unit in the Soil Survey of Sierra County Area, New Mexico (Neher, 1984). The county is located in the southwestern part of the State. The map scale is 1:48,000 for the portion of the survey under consideration. The mean annual precipitation is 200 to 250 mm, the potential evapotranspiration by the Thornthwaite method is about 1,300 mm, the mean annual air temperature is 14 to 18 °C, and the average frost-free period is 180 to 220 days. The majority of the land is used for livestock grazing, mainly cattle. Agricultural irrigation is practiced in less than 1 percent of the survey area.

Parent materials, landscape, and soil occurrence: The naming soils of the map unit are formed in transported sediments deposited on rock pediments. Slopes range from 1 to 15 percent. Areas are irregular and 70 to 200 ha in size. As much as 20 percent of the delineations consists in aggregate of Rock outcrop on hilltops and side slopes, small areas of Typic Haplargids on toe slopes and side slopes, and Petrocalcic Paleargids and Typic Paleorthids on low ridges at the lower elevations.

Generalized description: The representative pedon has a surface layer of brown (dry) fine sandy loam about 8 cm thick. The subsoil is strong brown sandy loam about 15 cm thick. The substratum is light brown very gravelly sandy loam about 8 cm thick over weathered sandstone 8 cm thick. Slightly altered sandstone is at a depth of about 40 cm.

Water related information: Saturated hydraulic conductivity is moderately slow to moderately high. Available water capacity is very low to low. Runoff is medium (Soil Survey Staff, 1951).

Agronomic information: The hazard of water erosion is moderate and that of wind erosion is high. The map unit is suited to livestock grazing, watershed, and wildlife habitat. The potential plant community is characterized by black gramma (*Bouteloua eropoda* (Torr.) Torr), bush muhly (*Muhlenbergia porteri* Scrib. Ex W.J. Beal), cane bluestem (*Bothriohloa barbinodis* (Lag.) Herter), and various woody plants. As the plant community deteriorates, there is an increase in three-awn (*Aristida* L.), broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britton and Ruoby), annual forbes, and woody plants. The average annual production ranges from 0.3 to 0.8 t ha^{-1}. Fences and pipelines for water are difficult to install because of the shallow depths to sandstone. The map unit is suited to livestock water developments and establishment of planned grazing

systems, but it is not suited to mechanical brush control and rangeland seeding.

Nonagricultural information: The soils of this mapping unit are very limited in their use for building sites, water management, and waste disposal systems because of the shallow depth to bedrock.

TABLE A-1

Water transmission rates, field water regime, and certain restrictive physical features and processes for Sharpsburg silty clay loam, 5 to 9 percent slopes, and Bakeoven-Condon complex, 2 to 20 percent slopes.

Property [a]	Map Unit	Depth cm	Value or Class
Saturated Hydraulic Conductivity	Sharpsburg	0-18	4-10 μm/s
		18-112	1-4 μm/s
		112-150	1-4 μm/s
	Bakeoven part	0-20	1-4 μm/s
	Condon part	0-66	4-10 μm/s
Hydrologic Group	Sharpsburg		B
	Bakeoven part		D
	Condon part		C
Bedrock Depth Hardness	Bakeoven part		13-30 cm, Hard
	Condon part		50-100 cm, Hard
Potential Frost Action	Sharpsburg		High
	Bakeoven part		Moderate
	Condon part		High

[a] No flooding. Free water occurrence >150 cm.

TABLE A-2

Particle size distribution and engineering classification for Sharpsburg silty clay loam, 5 to 9 percent slopes and Bakeoven-Condon complex, 2 to 20 percent slopes.

Property	Map Unit	Depth cm	Value or Class
USDA texture	Sharpsburg	0-18	Silty clay loam
		18-112	Silty clay loam, Silty clay
		112-150	Silty clay loam
	Bakeoven part	0-20	Very cobbly loam
		≥20	Unweathered bedrock
	Condon part	0-66	Silt loam
		≥66	Unweathered bedrock
>75 mm	Bakeoven part	0-20	25-45 pct
	Condon part	0-66	0 pct
Pass 4,10, 40, 200	Sharpsburg	0-18	100,100,100, 95-100 pct
		18-110	100,100,100, 95-100 pct
		110-150	100,100,100, 95-100 pct
	Bakeoven	0-20	30-75, 20-60,15-55,15-45
	Condon	0-66	100,100, 90-100, 80-90
Liquid Limit	Sharpsburg	0-18	35-55 pct
		18-112	35-60 pct
		112-150	35-50 pct
	Bakeoven	0-20	25-35 pct
	Condon	0-66	25-35 pct
Plastic Index	Sharpsburg	0-18	18-32 pct
		18-112	20-35 pct
		112-150	20-30 pct
	Bakeoven	0-20	5-10 pct
	Condon	0-66	5-10 pct

(continued next page)

TABLE A-2 (continued)

Property	Map Unit	Depth cm	Value or Class
Unified, AASHTO Classifications[a/]	Sharpsburg	0-18	CL, A-7
		18-112	CH, A-7
		112-150	CL, A-7
	Bakeoven	0-20	GM, A-1
	Condon	0-66	ML, A-4

[a/] Only first of the placements is given.

TABLE A-3

Physical and chemical interpretive properties for Sharpsburg silty clay loam, 5 to 9 percent slopes and Bakeoven-Condon complex, 2 to 20 percent slope.

Property	Map Unit	Depth cm	Value or Class
Available Water Capacity	Sharpsburg	0-18	0.21-0.23
		18-112	0.18-0.20
		112-150	0.18-0.20
	Bakeoven part	0-20	0.06-0.14
	Condon part	0-66	0.20-0.25
Reaction (pH)	Sharpsburg	0-18	5.1-6.5
		18-112	5.1-7.3
		112-150	6.1-7.3
	Bakeoven part	0-20	6.1-7.3
	Condon part	0-66	6.1-7.3
Salinity	Sharpsburg	0-18	<2 dSm^{-1}
		18-112	<2 dSm^{-1}
		112-150	<2 dSm^{-1}
	Bakeoven part	0-20	<2 dSm^{-1}
	Condon part	0-66	<2 dSm^{-1}
Shrink-swell Potential	Sharpsburg	0-18	Moderate
		18-112	High
		112-150	Moderate
	Bakeoven part	0-20	Low
	Condon part	0-66	Moderate

Table A-4

Erosion and corrosion quantities and classes for Sharpsburg silty clay loam, 5 to 9 percent slopes and Bakeoven-Condon complex, 2 to 20 percent slope.

Property	Map Unit	Depth cm	Value or Class
K	Sharpsburg	0-18	0.32
		18-112	0.43
		112-150	0.43
	Bakeoven part	0-20	0.10
	Condon part	0-66	0.43
T	Sharpsburg		5 t
	Bakeoven part		1 t
	Condon part		2 t
Wind Erodibility Group	Sharpsburg		7
Corrosion class:			
Uncoated steel	Sharpsburg		Moderate
	Bakeoven part		Moderate
	Condon part		Moderate
Concrete	Sharpsburg		Moderate
	Bakeoven part		Low
	Condon part		Low

TABLE A-5

Construction material suitability and building site evaluations for Sharpsburg silty clay loam, 5 to 9 percent slopes and Bakeoven-Condon complex, 2 to 20 percent slope.

Application [a]	Map Unit	Limitation Class and Restrictive Features
Roadfill	Sharpsburg	Poor: shrink-swell, low strength
	Bakeoven part	Poor: reclamation, thin layer,
	Condon part	Poor: reclamation, thin layer, frost action
Top soil	Sharpsburg	Fair: clayey
	Bakeoven part	Poor: thin layer, small stones
	Condon part	Fair: slope
Shallow excavations	Sharpsburg	Moderate: clayey
	Bakeoven part	Severe: depth to rock, small stones
	Condon part	Severe: depth to rock
Dwellings without basements	Sharpsburg	Severe: shrink-swell, low strength
	Bakeoven part	Severe: depth to rock
	Condon part	Moderate: slope, low strength, depth to rock

(continued next page)

TABLE A-5 (continued)

Application [a]	Map Unit	Limitation Class and Restrictive Features
Dwellings with basements	Sharpsburg	Severe: shrink-swell, low strength
	Bakeoven part	Severe: depth to rock
	Condon part	Severe: slope
Small commercial buildings	Sharpsburg	Severe: shrink-swell, low strength
	Bakeoven part	Severe: slope, depth to rock
	Condon part	Severe: slope
Local roads and streets	Sharpsburg	Severe: frost action, low strength
	Bakeoven part	Severe: depth to rock
	Condon part	Severe: frost action
Lawns and landscaping	Sharpsburg	Moderate: clayey

[a] All unsuited as sand and gravel sources.

TABLE A-6

Suitability class and limitations for sanitary facilities for Sharpsburg silty clay loam, 5 to 9 percent slopes and Bakeoven-Condon complex, 2 to 20 percent slope.

Application	Map Unit	Limitation Class and Restrictive Features
Septic tank absorption fields	Sharpsburg	Severe: slow percolation
	Bakeoven part	Severe: depth to rock, slow percolation
	Condon part	Severe: depth to rock
Sewage lagoon areas	Sharpsburg	Severe: slope
	Bakeoven part	Severe: slope, depth to rock
	Condon part	Severe: slope, depth to rock
Trench Sanitary Landfill	Sharpsburg	Severe: clayey
	Bakeoven part	Severe: depth to rock
	Condon part	Severe: depth to rock
Area Sanitary Landfill	Sharpsburg	Slight
	Bakeoven part	Moderate: slope
	Condon part	Moderate: slope
Daily Cover for Landfill	Sharpsburg	Poor: clayey
	Bakeoven part	Poor: thin layer, small stones
	Condon part	Fair: slope, thin layer

TABLE A-7

Water management limitations and class placements for Sharpsburg silty clay loam, 5 to 9 percent slopes and Bakeoven-Condon complex, 2 to 20 percent slope.

Application	Map Unit	Restrictive Features
Pond reservoir area	Sharpsburg	Slope, seepage
	Bakeoven part	Slope, depth to rock
	Condon part	Slope, depth to rock
Embankments, dikes, and levees	Sharpsburg	Hard to pack
	Bakeoven part	Thin layer, piping
	Condon part	Hard to pack, low strength, piping
Drainage	Sharpsburg	Not needed
	Bakeoven part	Not needed
	Condon part	Slope
Irrigation	Sharpsburg	Slope
	Bakeoven part	Slope, rooting depth
	Condon part	Slope, rooting depth
Terraces and Diversions	Sharpsburg	Erodes easily
	Bakeoven part	Depth to rock, slope
	Condon part	Depth to rock, slope
Grassed Waterways	Sharpsburg	Erodes easily
	Bakeoven part	Rooting depth, slope
	Condon part	Rooting depth

APPENDIX 3 Pedon Data

Pedons were sampled in each of the map units that are described in Appendix 2. Site data, a detailed soil profile description, and laboratory characterization data are given. Recorded field observations show several of the recently introduced measurements. Most measurements and classifications are discussed in Chapter 3. The observations are not inclusive of what should or could be done. For each pedon, selected laboratory data are given.

Sharpsburg Pedon Description

Location: Lancaster County, Nebraska, University of Nebraska, Rogers Farm 0.8 kilometers south and 4.5 kilometers east of Prairie Home; 378 m west and 74 m south of the northeast corner sec. 12; NW 1/4, NW 1/4, NE 1/4, NE 1/4, sec. 12, T10N, R8E.

Classification: fine, montmorillonitic, mesic Typic Argiudoll
Vegetation: Soybeans recently harvested
Parent material: Loess
Physiography: Lower side slope
Relief: 15 to 50 m
Elevation: 368 m
Slope: 5 percent
Aspect: 310° (NW)
Erosion: Slight
Drainage: Moderately well
Ground water: Deep
Salt or alkali: None
Stoniness: None

Described and sampled by: R.W. Fenwick and R.B. Grossman, November 7, 1988.

Soil Number: S88NE-109-020.

Remarks: The upper part of the soil is assumed to be developed in Wisconsin loess and the lower part in Illinoian loess. Part of the delineation lacked sufficient depth of a moist color value of 3 or less for a Mollisol probably because of postcultural erosion. A site was selected in a lower backslope position within a few tens of meters of alluvial fill where postcultural erosion had been relatively less. The position in the landscape is not typical for the naming soil of the map unit.

Ap1 - 0 to 8 cm; very dark brown (10YR 2/2) silty clay loam, dark grayish brown (10YR 4/2) dry; weak fine granular structure; slightly hard, friable; many fine and very fine roots; common fine vesicular pores; strongly acid[1/]; clear smooth boundary.

Ap2 - 8 to 18 cm; very dark brown (10YR 2/2) silty clay loam, dark grayish brown (10YR 4/2) dry; moderate medium subangular blocky structure; slightly hard, friable; many fine and very fine roots; common fine vesicular pores; strongly acid; abrupt smooth boundary.

A - 18 to 28 cm; dark grayish brown (10YR 3/2) silty clay loam, dark grayish brown (10YR 4/2) dry; weak medium subangular blocky structure; hard, friable; common fine roots; numerous worm casts; common fine tubular pores; moderately acid; clear smooth boundary.

BAt - 28 to 38 cm; dark grayish brown (10YR 3/2) silty clay loam, dark grayish brown (10YR 4/2) dry; moderate medium subangular blocky structure parting to moderate very fine subangular blocky; hard, friable; many fine roots; many fine tubular pores; few dark fillings in root channels; faint clay films on faces of peds; moderately acid; clear smooth boundary.

Bt1 - 38 to 51 cm; dark brown (10YR 3/3) silty clay loam, brown (10YR 5/3) dry; weak medium subangular blocky structure parting to moderate fine subangular blocky; hard, friable; common fine roots; few fine tubular pores; faint dark clay films on faces of peds; slightly acid; gradual smooth boundary.

Bt2 - 51 to 76 cm; brown (10YR 4/3) silty clay loam, brown (10YR 5/3) dry; weak medium prismatic structure parting to moderate fine subangular blocky; hard, firm; common fine roots; faint clay films on faces of peds; slightly acid; gradual smooth boundary.

BC1 - 76 to 94 cm; brown (10YR 4/3) and pale brown (10YR 6/3)

[1/] Low pH probably due to nitrogen fertilizer additions.

FIGURE A-1

Interrow on harvested soybeans, 35 to 40 percent covered by crop residue. Not compacted by traffic during harvest. Yellow object in photo is 5x2 cm in size.

silty clay loam, brown (10YR 5/3) and very pale brown (10YR 7/3) dry; few fine faint yellowish brown (10YR 5/6) iron concretions; moderate fine prismatic structure; hard, firm; few dark brown (10YR 3/3) coatings on faces of peds; few fine roots; slightly acid; gradual smooth boundary.

BC2 - 94 to 112 cm; brown (10YR 4/3) silty clay loam, brown (10YR 5/3) dry; few fine faint yellowish brown (10YR 5/4 and 5/6) iron concretions; weak medium prismatic structure; hard, firm; streaks of pale brown (10YR 6/3) and very dark grayish brown (10YR 3/2) along surfaces of peds; neutral; gradual smooth boundary.

BCb - 112 to 142 cm; brown (7.5YR 5/4) silty clay loam, light brown (7.5YR 6/4) dry; common fine faint yellowish brown (10YR 5/6 iron concretions; moderate medium prismatic structure; hard, friable; common coatings of dark brown (7.5YR 3/2) on surfaces of peds; neutral; gradual smooth boundary.

FIGURE A-2

Raindrop impact crust specimens from interrow which was compacted during harvest. Object in photo is 1 cm in length.

C - 142 to 178 cm; brown (7.5YR 4/4) and dark reddish brown (5YR 3/3) silty clay loam, light brown (7.5YR 6/4) and reddish brown (5YR 4/3 dry; few fine faint strong brown (7.5YR 5/6) iron concretions; massive; hard friable, neutral.

Surface, near surface: The sampling trench extended across four interrows. Figure A1 shows an interrow that did not undergo traffic and related compaction during harvest. The adjacent interrow to the right underwent traffic during harvest and related compaction. The other two interrows did not undergo traffic in harvest. Two of the interrows, including the one shown in figure A-1, are 35 to 40 percent covered by crop residue. The other two are 75 to 100 percent covered by crop residue. Linear roughness was measured based on 31 points, 5 cm apart. The standard deviation for the axis of the nontraffic interrow shown in figure 1 was 0.26 cm. For the adjacent interrow that underwent traffic during harvest, the standard deviation was 1.3 cm. Raindrop impact crust was present in convex locations.

FIGURE A-3

Two subhorizons of the Ap horizon of Sharpsburg silty clay loam. The Apl (0-8 cm) has been mechanically bulked and the Ap2 (8-16 cm) has been mechanically compacted.

Figure A-2 shows the crust specimen. Median rupture resistance of the crust was 5 N with a range of 5 to 7 N for eleven specimens. The crust was in the moderate class. The strongly reconstituted part of the crust was 1 to 2 mm thick. The crust in the concave interrow axis was somewhat weaker. The median was 4 N with a range of 2 to 5 N (weak to moderate) for 11 specimens. Thickness was 2 to 3 mm.

The Ap horizon consists of two subhorizons (fig. A3). The Ap1 had been subject recently to mechanical bulking and the Ap2 to mechanical compaction. The Ap2 averages 15 cm thick in the second interrow, which was subject to mechanical compaction during harvest. The other three interrows range narrowly in average thickness from 7 to 8 cm. Penetration resistance was measured at 17 points 5 to 10 cm apart where the Ap2 horizon was relatively strongly expressed. The median was 2.2 MPa with a range of 1.7 to 2.6 MPa. The water content was 22.1 percent. The suction should be between 1/3 and 2 bar (Baumer, 1986).

*** PRIMARY CHARACTERIZATION DATA ***
(LANCASTER COUNTY, NEBRASKA)

S88NE-109-020

PRINT DATE 11/06/90

SAMPLED AS : SHARPSBURG; FINE, MONTMORILLONITIC, MESIC, TYPIC ARGIUDOLL

NSSL - PROJECT 89P 18, LANCASTER CO
- PEDON 89P 85, SAMPLES 89P 770-779
- GENERAL METHODS 1B1A, 2A1, 2B

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
				(—— TOTAL		——)	(— CLAY	—)	(— SILT	—)	(——		SAND		——)	(– COARSE	FRACTIONS (MM)		–)	(>2MM)
																WEIGHT				WT
SAMPLE NO.	DEPTH (CM)	HORIZON		CLAY LT .002	SILT .002 -.05	SAND .05 -2	FINE LT .0002	CO3 LT .002	FINE .002 -.02	COARSE .02 -05	VF .05 -.10	F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	2 -5	5 -20	20 -75	.1 75	PCT OF WHOLE
				<—				PCT	OF <2MM	(3A1)					—>	<– PCT	OF	<75MM (3B1)	–	>SOIL
89P 770S	0- 8	Ap1		30.6	65.9	3.5			20.9	45.0	3.4	0.1	--	--	--	--	--	--	TR	--
89P 771S	8- 18	Ap2		33.1	63.5	3.4			21.0	42.5	3.3	0.1	--	--	--	--	--	--	TR	--
89P 772S	18- 28	A		37.8	59.1	3.1			21.4	37.7	3.1	--	--	--	--	--	--	--	--	--
89P 773S	28- 38	BAt		38.6	58.8	2.6			21.9	36.9	2.6	--	--	--	--	--	--	--	--	--
89P 774S	38- 51	Bt1		39.8	57.9	2.3			22.4	35.5	2.3	--	--	--	--	--	--	--	--	--
89P 775S	51- 76	Bt2		38.0	60.1	1.9			24.9	35.2	1.9	--	--	--	--	--	--	--	--	--
89P 776S	76- 94	Bc1		31.1	65.3	3.6			30.7	34.6	2.2	0.8	0.4	0.2	--	--	--	--	--	--
89P 777S	94- 112	Bc2		31.0	64.5	4.5			31.3	33.2	2.2	1.3	0.9	0.1	--	--	--	--	1	--
89P 778S	112- 142	Bcb		32.2	62.0	5.8			29.2	32.9	3.1	1.5	1.0	0.2	--	--	--	--	2	--
89P 779S	142- 178	C		31.8	61.9	6.3			26.1	35.8	3.2	1.7	1.2	0.2	--	--	--	--	3	--

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MN	EXTR P 6S3 PPM	TOTAL S 6R3A <—	(—— DITH-CIT EXTRACTABLE FE 62CB PERCENT	AL 6G/A OF <2MM	MN 6D2A ——>)	(RATIO/CLAY) CEC 8D1	15 BAR 8D1	(ATTERBERG) – LIMITS – LL 4F1 PCT	PI 4F < 0.4MM	(– BULK FIELD MOIST 4A3A <——	DENSITY 1/3 BAR 4A1D G/CC	–) OVEN DRY 4A1H ——>	COLE WHOLE SOIL 4D1 CM/CM	(—— WATER FIELD MOIST 4B4 <——	1/10 BAR 4B1C PCT OF	CONTENT 1/3 BAR 4B1C <2MM	——) 15 BAR 4B2a ——>	WRD WHOLE SOIL 4C1 CM/CM
0- 8	2.05								0.39										11.9	
8- 18	1.80								0.44										14.4	
18- 28	1.68								0.44										16.8	
28- 38	1.32								0.45										17.2	
38- 51	1.02								0.44										17.5	
51- 76	0.56								0.44										16.7	
76- 94	0.38								0.45										14.1	
94- 112	0.43								0.43										13.4	
112- 142	0.56								0.42										13.5	
142- 178	0.49								0.43										13.7	

ANALYSES: ALL ON SIEVED <2MM BASIS

*** PRIMARY CHARACTERIZATION DATA ***

S88NE-109-020

SAMPLED AS: SHARPSBURG; FINE, MONTMORILLONITIC, MESIC, TYPIC ARGIUDOLL
NATIONAL SOIL SURVEY LABORATORY PEDON 89P 85, SAMPLE 89P 770-779

PRINT DATE 11/06/90

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
	(—— NH4OAC EXTRACTABLE BASES ——)							(—— CEC ——)										(—— PH ——)		
DEPTH (CM)	CA 5B5A 6N2E	MG 5B5A 6O2D	NA 5B5A 6P2B	K 5BA5 6Q2B	SUM BASES	ACID-ITY 6H5A	EXTR AL 6G9B	SUM CATS 5A3A	NH4-OAC 5A8B	BASES + AL 5A3B	AL SAT 5G1	-BASE SUM 5C3	SAT-NH4 OAC 5C1	CO3 AS CACO3 <2MM 6E1G	RES. OHMS /CM 8E1		COND MMHOS /CM 81		CACL2 .01M 8C1F 1:2	H2O 8C1F 1:1
	<—— MEQ / 100 G ——>										<—— PCT ——>									
0- 8																			4.8	5.4
8- 18																			4.5	5.3
18- 28																			4.7	5.6
28- 38																			5.3	5.9
38- 51																			5.4	6.3
51- 76																			5.7	6.2
76- 94																			5.9	6.5
94-112																			6.1	6.6
112-142																			6.1	6.8
142-178																			6.2	6.8

Bakeoven - Condon

Two pedons were sampled for laboratory characterization in the vicinity of the typifying sites of the map unit for the soil survey area. The pedons occur on a convex ridge about 150 m wide that trends northeast to southwest. The area has moderately deep soils on mounds (Condon) and soils that are shallow to bedrock between the mounds (Bakeoven). Mounds occupy about 30 percent of the area shown in figure A-4. Figure A-5, an area of 0.36 ha within which the pedons were sampled, is a photograph that shows the pattern of mounds. The mounds are 15 to 20 m in diameter and 1 to 2 m high. In all probability, the origin is related to periglacial processes combined with movement by wind of finer materials (Green, 1982). The area generally slopes to the west, except for the southeast corner which slopes to the east, and is 40 m from the break to very steep side slopes of the Deschutes River Canyon. Figure A-6 shows the pedon of Bakeoven.

Bakeoven Pedon Description

Location: Wasco County, Oregon, 550 m south and 315 m east of the northwest corner of sec. 15; NE 1/4, SW 1/4, sec. 15, T. 35 R14W. Latitude 45° 18′ 59″ N. Longitude 121° 03′ 57″ W.

Classification: loamy-skeletal, mixed, mesic Lithic Haploxeroll
Vegetation: Range
Sandberg bluegrass (*Poa secunda* J. Presl.) - 45 percent
Stiff sagebrush (*Artemisia rigida* (Nutt.) Gray) - 20 percent
Phlox (*Phlox* L.) - 5 percent
Buckwheat (*Eriogonum* Michx.) - 5 percent
Blue-eyed Mary (*Collinsia parviflora* Lindlo)
Parent material: Mixed water and wind-transported soil material from the underlying basalt
Physiography: Intermound, part of ridgetop plateau
Relief: .5 to 1.5 meters
Elevation: 1,000 meters
Slope: 4 percent
Aspect: 220° (SW)
Erosion: Moderate
Drainage: Well-drained
Ground Water: Very deep
Salt or alkali: None
Stoniness: 2 percent

Described and sampled by: R. Fenwick, R. W. Langridge, and R.B. Grossman, April 4, 1989.

Soil number: S89OR-065-001.

Remarks: Soil Thickness is approximately 5 to 10 cm greater under the sagebrush canopy than outside the canopy.

*** PRIMARY CHARACTERIZATION DATA ***
(WASCO COUNTY, OREGON)

S89OR-065-001 PRINT DATE 11/06/90

SAMPLED AS: BAKEOVEN; LOAMY-SKELETAL, MIXED, MESIC LITHIC HAPLOXEROLL

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

NSSL - - PROJECT 89P 102, MANUAL CHAR
- PEDON 89P 524, SAMPLES 89P2917-2921
- GENERAL METHODS 1B1A, 2A1, 2B

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
				(—— TOTAL		——)	(— CLAY	—)	(— SILT	—)	(——		SAND		——)	(- COARSE	FRACTIONS (MM)		-)	(>2MM)
																	WEIGHT			WT
SAMPLE NO.	DEPTH (CM)	HORIZON		CLAY LT .002	SILT .002 -.05	SAND .05 -2	FINE LT .0002	CO3 LT .002	FINE .002 -.02	COARSE .02 -05	VF .05 -.10	F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	2 -5	5 -20	20 -75	.1 75	PCT OF WHOLE
				<——					PCT OF	<2MM	(3A1)				——>	<— PCT	OF	<75MM(3B1)	——>	SOIL
89P2917M	0- 5	A		5.4	23.6	71.0			11.5	12.1	8.7	9.5	9.8	21.2	21.8	17	4	--	70	21
89P2918M	5- 13	AB		8.3	31.5	60.2			17.0	14.5	11.2	9.6	8.5	16.1	14.8	15	2	15	65	22
89P2919M	13- 20	Bw		11.7	29.4	58.9			16.3	13.1	9.8	9.6	8.7	15.8	15.0	13	17	--	64	30
89P2920M	20- 30	2R														--	--	--		--
89P2921M	0- 20															6	4	60		74

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MN	EXTR P 6S3 PPM	TOTAL S 6R3A <—	(—— DITH-CIT FE 62CB PERCENT	AL 6G7A OF <2MM	——) MN 6D2A ——>	(RATIO/CLAY) CEC 8D1	15 BAR 8D1	(ATTERBERG) LL 4F1 PCT	PI 4F < 0.4MM	(- BULK FIELD MOIST 4A3A <——	DENSITY 1/3 BAR 4A1D G/CC	-) OVEN DRY 4A1H ——>	COLE WHOLE SOIL 4D1 CM/CM	(—— FIELD MOIST 4B4 <——	WATER 1/10 BAR 4B1C PCT OF	CONTENT 1/3 BAR 4B1C <2MM	——) 15 BAR 4B2a ——>	WRD WHOLE SOIL 4C1 CM/CM
0- 5	0.77				2.2	0.1	0.1	2.56	0.98										5.3	
5- 13	0.65				2.5	0.1	0.1	1.95	0.75										6.2	
13- 20	0.84				2.7	0.1	0.1	1.71	0.70										8.2	
20- 30																				
0- 20																			6.9	

AVERAGES, DEPTH 0-20: PCT CLAY 9 PCT .1-75MM 66

*** PRIMARY CHARACTERIZATION DATA ***

S89OR-065-001

PRINT DATE 11/06/90

SAMPLED AS: BAKEOVEN; LOAMY-SKELETAL, MIXED, MESIC LITHIC HAPLOXEROLL
NATIONAL SOIL SURVEY LABORATORY PEDON 89P 524, SAMPLE 89P2917-2921

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
	(—— NH4OAC EXTRACTABLE BASES				——)			(—— CEC		——)								(—— PH		——)
DEPTH (CM)	CA 5B5A 6N2E	MG 5B5A 6O2D	NA 5B5A 6P2B	K 5BA5 6Q2B	SUM BASES	ACID-ITY 6H5A	EXTR AL 6G9b	SUM CATS 5A3A	NH4-OAC 5A8B	BASES + AL 5A3B	AL SAT 5G1	-BASE SUM 5C3	SAT- NH4 OAC 5C1	CO3 AS CACO3 A<2MM 6E1G	RES. OHMS /CM 8E1		COND MMHOS /CM 81	NAF 8C1D	CACL2 .01M 8C1F 1:2	H2O 8C1F 1:1
	<——				MEQ / 100	G			——>	<——		PCT	——	——>						
0- 5	8.2	3.7	TR	0.3	12.2	3.1		15.3	13.8			80	88					9.4	6.4	7.2
5- 13	9.6	4.4	TR	0.2	14.2	5.6		19.8	16.2			72	88					10.0	6.4	7.2
13- 20	12.2	5.6	TR	0.1	17.9	4.7		22.6	20.0			79	89					10.1	6.0	6.9
20- 30						3.8		3.8												
0- 20																				

	(—— SPODIC HORIZON CRITERIA						——)
	(—— NA PYROPHOSPHATE EXTRACTABLE					——)	INDEX
DEPTH (CM)	C 6A4A	FE 6C8A	AL 6G10	FE+AL DI-CI FE+AL	FE+AL (—— DIVIDED BY PCT CLAY	AL+C ——) PCT CLAY	OF ACCUM
	<—— PCT OF <2MM		——>				
0- 5		TR	TR				
5- 13		TR	--				
13- 20		0.1	0.1	0.1			
20- 30							
0- 20							

ANALYSES: M= ALL ON SIEVED <2MM BASIS

*** PRIMARY CHARACTERIZATION DATA ***
(WASCO COUNTY, OREGON)

S89OR-065-001 PRINT DATE 11/06/90

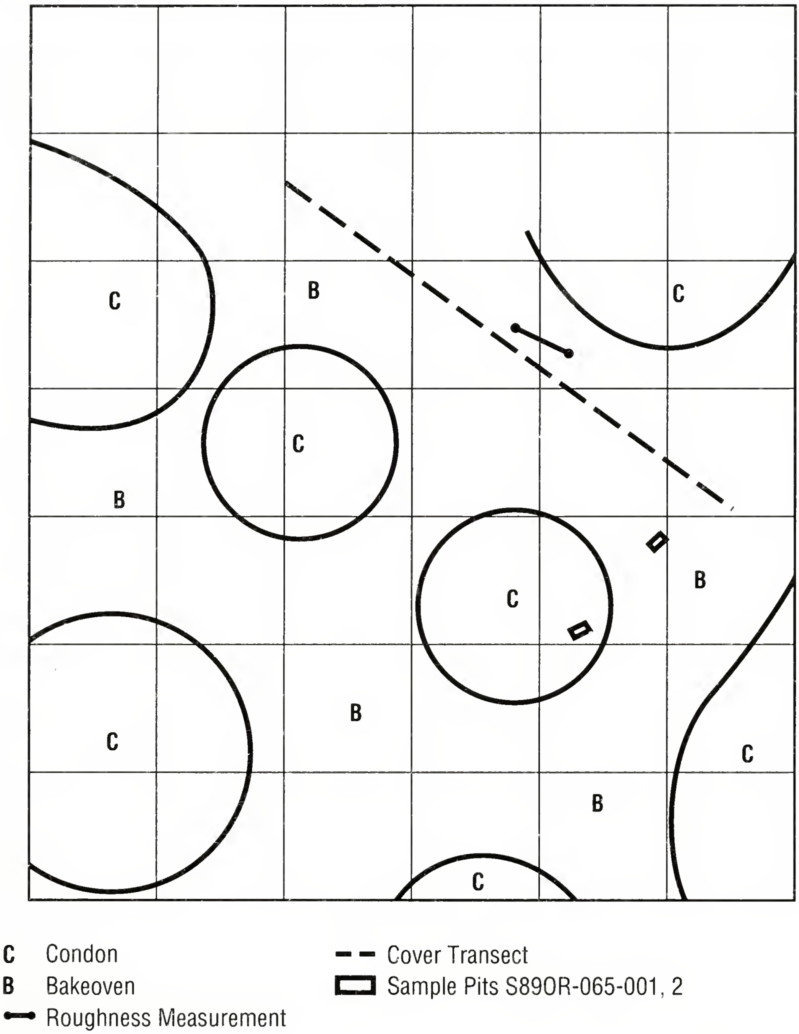
SAMPLED AS: BAKEOVEN; LOAMY -SKELETAL, MIXED, MESIC LITHIC HAPLOXEROLL

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

NSSL - - PROJECT 89P 102, MANUAL CHAR
- PEDON 89P 524, SAMPLES 89P2917-2921
- GENERAL METHODS 1B1A, 2A1, 2B

		-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
		ACID	OXALATE	EXTRACTION		PHOSPHOUS		KCL	TOTAL	(—— WATER CONTENT ——)				(—— WATER DISPERSIBLE ——)						MIN	AGGRT
		OPT	FE	SI	AL		CIT-	MN	C	0.06	1-	2-	15	<—— PIPETTE ——>			<—— HYDROMETER ——>			SOIL	STABL
		DEN				RET	ACID			BAR	BAR	BAR	BAR	CLAY	SILT	SAND	CLAY	SILT	SAND	CONT	<5mm
SAMPLE	HZ	8J	6C9a	6V2	6G12	6S4	6S5	6D3	6A2d	4B1c	4B1a	4B1a	4B2b	<—— 3A1c ——>			<—— SML ——>			8F1	4G1
NO.	NO		<—— PCT OF <2MM ——>				<—— PPM ——>		<—— PCT OF <2MM ——>												<PCT>
89P2917	1	0.16	1.93	0.18	0.16	16							5.5	4.6	25.4	69.9					
89P2918	2	0.17	2.03	0.19	0.17	23							6.2	5.7	31.5	62.7					
89P2919	3	0.19	1.84	0.20	0.20	25							8.0	8.7	31.1	60.1					
89P2920	4																				
89P2921	5												6.9								

FIGURE A-4



Sketch map of the area where the Bakeoven and Condon pedons were described and sampled. Cells are 10m on edge.

FIGURE A-5

Landscape of the Bakeoven-Condon complex mapping unit showing pattern of mounds (Condon) and intermounds (Bakeoven).

FIGURE A-6

Profile of Bakeoven very cobbly sandy loam.

A - 0 to 5 cm; dark brown (7.5YR 3/3) very cobbly sandy loam, brown (7.5YR 4/4) dry; weak fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; 35 percent pebbles, 20 percent cobbles, and 5 percent stones; neutral; clear smooth boundary.

AB - 5 to 13 cm; dark reddish brown (5YR 3/3) very cobbly sandy loam, dark reddish brown (5YR 3/4) dry; weak fine subangular blocky structure, breaking to weak fine granular; slightly hard, friable, slightly sticky and slightly plastic; common fine and very fine and few medium roots; many very fine irregular pores; 20 percent pebbles, 35 percent cobbles, and 3 percent stones; neutral; clear smooth boundary.

Bw - 13 to 20 cm; dark reddish brown (5YR 3/3) extremely cobbly sandy loam, dark reddish brown (5YR 3/4) dry; weak fine subangular blocky structure; hard, friable, sticky and plastic; common fine and very fine and few medium roots concentrated along faces of rock fragments; common very fine tubular pores; 20 percent pebbles, 50 percent cobbles, and 2 percent stones; neutral; abrupt wavy boundary.

2R - 20 cm; basalt.

Surface, near surface: The ground surface consists of 10-20 percent sagebrush and 80-90 percent intershrub. Figure A-7 shows the intershrub. Small mounds of soil material, low in rock fragments, are associated with the sage brush. Soil thickness is approximately 5 to 10 cm greater under the sagebrush canopy than outside the canopy. Bare areas 20 to 40 cm across occur. Most are recessed 5 to 10 cm below the vegetated parts. A minority of the bare areas are higher than the surrounding vegetated area and may be recently affected by frost action. The following is a numerical description of the cover for the shrub and intershrub components separately based on point counts.

Component Kind	Mulch			Canopy[a/]		Rock Fragments		Area	
	Area	>2mm	Total	Effectiveness	Height	>250 mm	75-250 mm	5-75 mm	2-5 mm
	pct	pct	pct	pct	m	pct	pct	pct	pct
Shrub	17	0	20	70	1/2	—	—	—	—
Inter-shrub	83	13	27	—	—	0	Tr	49	51

[a/] Percent of rain drops assumed intercepted.

The soil-loss ratio (Wischmeier and Smith, 1978) of the shrub was 0.04 and the intershrub 0.16. The weighted average overall soil-loss ratio is 0.14. Roughness of the intershrub area was measured based on 31 points 10 cm apart with a correction for slope. The standard deviation was 1.3 cm. The overall color value of the dry ground surface, inclusive of the rock fragments, was 4.

FIGURE A-7

Close-up photo of ground surface near sample pit for Bakeoven very cobbly sandy loam component of Bakeoven-Condon complex. Yellow marker object is 5x5x2 cm in size.

Condon Pedon Description

Location: Wasco County, Oregon, 550 m south and 310 m east of northwest corner sec. 15; NE 1/4, SW 1/4, NW 1/4, sec. 15, T3S, R14W. Latitude 45° 18′ 59″ N. Longitude 121° 03′ 57″ W.

Classification: fine-loamy, mixed, mesic Typic Haploxeroll
Vegetation: Range
Idaho fescue (*Festuca idahoensis* Elmer) - 30 percent
Cheatgrass - 25 percent
Sandberg bluegrass (*Poa secunda* J. Presl.) - 20 percent
Hanging pod (milk-vetch (A. filipes))- 10 percent
Bluebunch wheatgrass (*Agropyron spicatum* (Scribn and J.G. Smith) A. Heller) - 5 percent
Other
Lipine (*Lupinus* L.)
Yarro (*Achiller* L.)
Buckwheat (*Eriogunum* Michx)
Parent material: Mixed loess and pedisediments
Physiography: Ridgetop plateau, biscuit (mound)
Relief: .5 to 1.5 meters
Elevation: 1,000 meters
Slope: 8 percent Aspect: 120° (SE)
Erosion: Moderate
Drainage: Well-drained
Ground water: Very deep
Salt or alkali: None
Stoniness: None

Described and sampled by: R. W. Fenwick, R.B. Grossman, and R. W. Langridge April 28, 1989.

Soil number S89OR-065-002

A - 0 to 8 cm; dark brown (7.5 YR 3/2) loam, brown (7.5 YR 4/3) dry; weak fine subangular blocky structure parting to weak fine granular; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; 5 percent pebbles; neutral; clear smooth boundary.

AB - 8 to 18 cm; dark brown (7.5 YR 3/2) loam, brown (7.5 YR 4/3) dry; weak medium and fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine roots; many very fine irregular pores; 5 percent pebbles; neutral; clear smooth boundary.

Bw1 - 18 to 38 cm; dark brown (7.5 YR 3/3) loam, brown (7.5 YR 4/3) dry; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few very fine roots; many very fine tubular pores; 5 percent pebbles; neutral; clear smooth boundary.

Bw2 - 38 to 58 cm; dark brown (7.5 YR 3/3) loam, brown (7.5 YR 4/3) dry; weak coarse subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few very fine roots; many very fine tubular pores; 5 percent pebbles; neutral; clear wavy boundary.

BC - 58 to 66 cm; dark brown (7.5 YR 3/3) loam, brown (7.5 YR 4/3) dry; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few very fine roots; common very fine tubular pores; 5 percent pebbles; neutral; abrupt wavy boundary.

2R - 66 cm; fractured basalt.

Surface, near surface: The outermost 1 to 3 m of the mounds (about half of the mound area) was subject to more traffic by grazing animals than the central portion. The outer portion has 30 to 40 percent bare soil compared to 10 percent or less in the central portion. The soil-loss ratio (Wischmeier and Smith, 1978) is 0.18 for the periphery and 0.07 for the central part.

*** PRIMARY CHARACTERIZATION DATA ***
(WASCO COUNTY, OREGON)

S89OR-065-002

PRINT DATE 11/06/90

SAMPLED AS : CONDON, FINE-SILTY, MIXED, MESIC TYPIC HAPLOXEROLL
REVISED TO : CONDON, FINE-LOAMY, MIXED, MESIC TYPIC HAPLOXEROLL

NSSL - - PROJECT 89P 102. MANUAL CHAR
- PEDON 89P 525, SAMPLES 89P2922-2926
- GENERAL METHODS 1B1A, 2A1, 2B

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

	-1--	-2--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
			(—— TOTAL		——)	(—— CLAY	——)	(—— SILT	——)	(——		SAND		——)	(— COARSE FRACTIONS (MM) —)				(>2MM)
SAMPLE NO.	DEPTH (CM)	HORIZON	CLAY LT .002	SILT .002 -.05	SAND .05 -2	FINE LT .0002	CO3 LT .002	FINE .002 -.02	COARSE .02 -05	VF .05 -.10	F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	WEIGHT 2 -5	5 -20	20 -75	.1 75	WT PCT OF WHOLE >SOIL
			<——				PCT	OF <2MM	(3A1)					——>	<— PCT	OF	<75MM(3B1)	—	
89P2922M	0- 8	A	9.2	33.0	57.8			16.0	17.0	10.9	9.8	7.1	11.4	18.6	20	6	--	61	26
89P2923M	8- 18	AB	9.6	34.7	55.7			18.3	16.4	10.2	10.5	7.9	13.0	14.1	19	5	--	59	24
89P2924M	18- 38	Bw1	9.5	31.7	58.8			17.8	13.9	9.4	9.2	8.2	16.4	15.6	18	4	--	61	22
89P2925M	38- 58	Bw2	11.2	32.7	56.1			19.0	13.7	8.7	9.4	7.4	13.7	16.9	18	5	--	59	23
89P2926M	58- 66	BC	11.2	35.4	53.4			19.1	16.3	9.5	10.8	8.6	13.0	11.5	19	4	1	57	24

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MN	EXTR P 6S3 PPM	TOTAL S 6R3A <——	(—— DITH-CIT EXTRACTABLE FE 62CB PERCENT	AL 6G7A OF <2MM	MN 6D2A ——>)	(RATIO/CLAY) CEC 8D1	15 BAR 8D1	(ATTERBERG) — LIMITS — LL 4F1 PCT	PI 4F < 0.4MM	(— BULK DENSITY —) FIELD MOIST 4A3A <——	1/3 BAR 4A1D G/CC	OVEN DRY 4A1H ——>	COLE WHOLE SOIL 4D1 CM/CM	(—— WATER CONTENT ——) FIELD MOIST 4B4 <——	1/10 BAR 4B1C PCT	1/3 BAR 4B1C OF <2MM	15 BAR 4B2a ——>	WRD WHOLE SOIL 4C1 CM/CM
0- 8	1.50				2.5	0.1	0.1	1.96	0.84										7.7	
8- 18	0.83				2.5	0.1	0.1	1.72	0.74										7.1	
18- 38	0.54				2.4	0.1	0.1	1.81	0.76										7.2	
38- 58	0.43				2.5	0.1	0.1	1.64	0.67										7.5	
58- 66	0.50				2.7	0.1	0.1	1.64	0.80										9.0	

ANALYSES: M= ALL ON SIEVED <2MM BASIS

*** PRIMARY CHARACTERIZATION DATA ***

S89OR-065-002 PRINT DATE 11/06/90

SAMPLED AS: CONDON; FINE-SILTY, MIXED, MESIC TYPIC HAPLOXEROLL
NATIONAL SOIL SURVEY LABORATORY; PEDON 89P 525, SAMPLE 89P2922-2926

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
	(—— NH4OAC EXTRACTABLE BASES ——)					ACID-	EXTR	(—— CEC ——)			AL	-BASE	SAT-	CO3 AS	RES.		COND.	(—— PH ——)		
DEPTH (CM)	CA 5B5A 6N2E	MG 5B5A 602D	NA 5B5A 6P2B	K 5BA5 6Q2B	SUM BASES	ITY 6H5A	AL 6G9B	SUM CATS 5A3A	NH4- OAC 5A8B	BASES + AL 5A3B	SAT 5G1	SUM 5C3	NH4 OAC 5C1	CACO3 <2MM 6E1G	OHMS /CM 8E1		MMHOS /CM 81	NAF 8C1D	CACL2 .01M 8C1F A:2	H20 8C1F 1:1
	<—— MEQ / 100 G ——>									<—— PCT ——>										
0- 8	11.2	4.2	TR	1.0	16.4	3.7		20.1	18.0			82	91					9.9	6.4	7.1
8- 18	10.2	4.3	--	0.6	15.1	3.8		18.9	16.5			80	92					9.9	6.2	7.3
18- 38	10.4	5.0	TR	0.2	15.6	3.8		19.4	17.2			80	91					10.0	6.2	7.0
38- 58	11.2	5.8	TR	0.1	17.1	3.1		20.2	18.4			85	93					10.0	6.3	7.2
58- 66	11.5	5.9	TR	0.1	17.5	3.2		20.7	18.4			85	95					9.9	6.4	7.0

	(—— SPODIC HORIZON CRITERIA ——)						
	(—— NA PYROPHOSPHATE EXTRACTABLE ——)						INDEX
	C	FE	AL	FE+AL	FE+AL	AL+C	OF
				(—— DIVIDED BY ——)			ACCUM
DEPTH (CM)	6A4A	6C8A	6G10	DI-CI	PCT	PCT	
	<—— PCT OF <2MM ——>			FE+AL	CLAY	CLAY	
0- 8		0.1	TR	TR	TR		
8- 18		0.1	0.1	0.1			
18- 38		TR	0.1	TR	TR		
38- 58		TR	TR				
58- 66		0.1	TR	TR	--		

*** PRIMARY CHARACTERIZATION DATA ***
(WASCO COUNTY, OREGON)

S89OR-065-002

SAMPLED AS: CONDON; FINE-SILTY, MIXED, MESIC TYPIC HAPLOXEROLL

PRINT DATE 11/06/90

NSSL - - PROJECT 89P 102, MANUAL CHAR
- PEDON 89P 525, SAMPLES 89P2922-2926
- GENERAL METHODS 1B1A, 2A1, 2B

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

		-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
		ACID	OXALATE	EXTRACTION		PHOSPHOUS		KCL	TOTAL	(—— WATER CONTENT ——)				(—— WATER DISPERSIBLE ——)						MIN	AGGRT
SAMPLE NO.	HZ NO	OPT DEN	FE	SI	AL	RET	CIT-ACID	MN	C	0.06 BAR	1-BAR	2-BAR	15 BAR	<—— PIPETTE ——>			<—— HYDROMETER ——>			SOIL CONT	STABL <5mm
														CLAY	SILT	SAND	CLAY	SILT	SAND		
		8J	6C9a	6V2	6G12	6S4	6S5	6D3	6A2d	4B1c	4B1a	4B1a	4B2b	<—— 3A1c ——>			<—— SML ——>			8F1	4G1
			<—— PCT OF <2MM ——>			<—— PPM ——>			<—— PERCENT OF <2MM ——>												><PCT>
89P2922	1	0.21	1.57	0.16	0.15	12							8.0	5.9	33.1	61.0					
89P2923	2	0.18	1.64	0.18	0.14	19							7.1	6.4	36.9	56.6					
89P2924	3	0.15	1.38	0.17	0.15	17							7.3	7.5	33.5	59.0					
89P2925	4	0.15	1.47	0.19	0.16	24							8.1	8.5	34.1	57.3					
89P2926	5	0.16	1.44	0.18	0.17	21							9.0	9.8	38.1	52.1					

Lithic Haplargid

Location: Sierra County, New Mexico, L/7 Ranch; 11.3 kilometers south and 2.4 kilometers west of Engle; 640 m northwest of L/7 Ranch headquarters; 160 m east and 1040 m north of the southwest corner sec. 21; SE 1/4, SW 1/4, NW 1/4, sec. 21, T14S, R2W. Latitude 33°04′42″ north, Longitude 107°03′28″ west.

Classification: loamy, mixed, thermic Lithic Haplargid
Vegetation: Range (mesquite, mixed grasses and shrubs)
Parent material: Sandstone and eolain material
Physiography: Valley slope of plateau
Relief: 1 to 5 m
Elevation: 1,460 m
Slope: 3 percent
Aspect: 75° (NE)
Erosion: Moderate
Drainage: Well drained
Ground water: Deep
Salt or alkali: None
Stoniness: None

Described by: R. Fenwick, R.B. Grossman, and C. Montoya, April 24, 1989.

Soil number: S89NM-051-001

A - 0 to 4 cm; yellowish red (5YR 4/6) sandy loam, reddish brown (5YR 4/4) moist; weak fine granular structure; soft, friable, nonsticky, nonplastic; few very fine and fine roots; 5 percent fine pebbles; very slightly effervescent; moderately alkaline; abrupt smooth boundary.

Bt - 4 to 13 cm; yellowish red (5YR 4/8) sandy clay loam, yellowish red (5YR 4/6) moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, firm, slightly sticky, plastic; common faint clay films in pores and clay bridging sand grains; few fine, irregular soft masses of carbonates; few very fine and fine roots; few fine tubular pores; 5 percent fine pebbles; strongly effervescent, strongly alkaline; clear smooth boundary.

Btk - 13 to 23 cm; yellowish red (5YR 4/8) clay loam, yellowish red (5 YR 4/6) moist; moderate medium subangular blocky structure; hard, firm, slightly sticky, plastic; common faint clay films on faces of peds and clay bridging sand grains; common fine platelike soft filaments and

masses of carbonates; few fine and very fine roots; few fine tubular pores; 5 percent fine pebbles; violently effervescent; moderately alkaline; clear wavy boundary.

BCk - 23 to 35 cm; grayish brown (10YR 5/2) and reddish brown (5YR 5/3) gravelly clay loam; massive; hard, firm; common medium and coarse irregular soft masses of carbonates; 20 percent pebbles; very few fine roots; violently effervescent; moderately alkaline; abrupt wavy boundary.

2R1 - 35 to 43 cm; hard olive gray (5Y 5/2) fractured sandstone; fracture surfaces coated with reddish brown (5YR 5/3) coatings; carbonate as few small pendents on underside of fragments.

2R2 - 43 cm; moderately hard, olive gray (5Y 5/2) thinly bedded sandstone.

A numerical description follows of the cover for the shrub and intershrub components separately. Areal percentages were obtained by point counting.

Component	Mulch			Canopy		Rock Fragments Size			
Kind	Area	>2mm	Total	Effectiveness	Height	>250 mm	75 mm	5 mm	2 mm
	pct	pct	pct	pct	m	pct	pct	pct	pct
Shrub	10	0	100	50	<1/2	—	—	—	—
Inter-shrub	90	20	68	0		0	4	34	62

Based on the cover information, the soil-loss ratio (Wischmeier and Smith, 1978) was 0.27 for the shrub component and 0.52 for the intershrub. The overall soil-loss ratio was 0.48. The soil-loss ratio may be slightly lower during July and August, the period of maximum water erosion, because of more vegetation.

Roughness was determined for 31 points, 5 cm apart in a bare area that was relatively smooth along the assumed direction of overland flow. The standard deviation corrected for slope was 0.34 cm. The dry rupture resistance of the crust was 3N based on the average of nine determinations from each of two places a few meters apart. The thickness of the reconstituted part of the crust was 1 to 2 mm.

*** PRIMARY CHARACTERIZATION DATA ***
(SIERRA COUNTY, NEW MEXICO)

S89NM-051-001

PRINT DATE 11/06/90

SAMPLED AS : LITHIC HAPLARGID
REVISED TO : LOAMY, MIXED, THERMIC LITHIC HAPLARGID

NSSL - PROJECT 89P 102, MANUAL CHAR
- PEDON 89P 523, SAMPLES 89P2911-2916
- GENERAL METHODS 1B1A, 2A1, 2B

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
				(—— TOTAL		——)	(— CLAY	—)	(— SILT	—)	(——		SAND		——)	(– COARSE	FRACTIONS (MM)		–)	(>2MM)
																WEIGHT				WT
SAMPLE NO.	DEPTH (CM)	HORIZON		CLAY LT .002	SILT .002 -.05	SAND .05 -2	FINE LT .0002	CO3 LT .002	FINE .002 -.02	COARSE .02 -05	VF .05 -.10	F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	2 -5	5 -20	20 -75	.1 75	PCT OF WHOLE
				<——				PCT	OF <2MM	(3A1)					——>	<– PCT	OF	<75MM (3B1)	–	>SOIL
89P2911S	0- 4	A		9.7	10.9	79.4			6.1	4.8	10.8	27.3	24.5	12.7	4.1	2	4	--	70	6
89P2912S	4- 13	BT		31.8	19.1	49.1		1.1	11.1	8.0	11.6	20.8	13.0	3.1	0.6	5	2	--	42	7
89P2913S	13- 23	BtK		31.0	24.0	45.1		2.3	16.1	7.9	10.9	14.3	10.7	5.7	3.4	16	1	--	45	17
89P2914S	23- 35	BCK														25	13	--		38
89P2915S	35- 43	2R1														--	--	--		--
89P2916S	43- 50	2R2														--	--	--		--

DEPTH (CM)	ORGN C 6A1C PCT	TOTAL N 6B3A <2MN	EXTR P 6S3 PPM	TOTAL S 6R3A <——	(—— DITH-CIT EXTRACTABLE FE 6C2B PERCENT	AL 6G7A OF <2MM	MN 6D2A ——>)	(RATIO/CLAY) CEC 8D1	15 BAR 8D1)	(ATTERBERG – LIMITS – LL 4F1 PCT	PI 4F < 0.4MM)	(– BULK FIELD MOIST 4A3A <——	DENSITY 1/3 BAR 4A1D G/CC	OVEN DRY 4A1H ——>–)	COLE WHOLE SOIL 4D1 CM/CM	(—— WATER FIELD MOIST 4B4 <——	1/10 BAR 4B1C PCT OF	CONTENT 1/3 BAR 4B1C <2MM	15 BAR 4B2a ——>)	WRD WHOLE SOIL 4C1 CM/CM
0- 4	0.15							1.05	0.46										4.5	
4- 13	0.34							0.60	0.36										11.3	
13- 23	0.35							0.64	0.37										11.5	
23- 35	0.61																		10.1	
35- 43																				
43- 50																				

AVERAGES, DEPTH 4-23: PCT CLAY 30 PCT .1-75MM 43p

*** PRIMARY CHARACTERIZATION DATA ***

S89NM-051-001

PRINT DATE 11/06/90

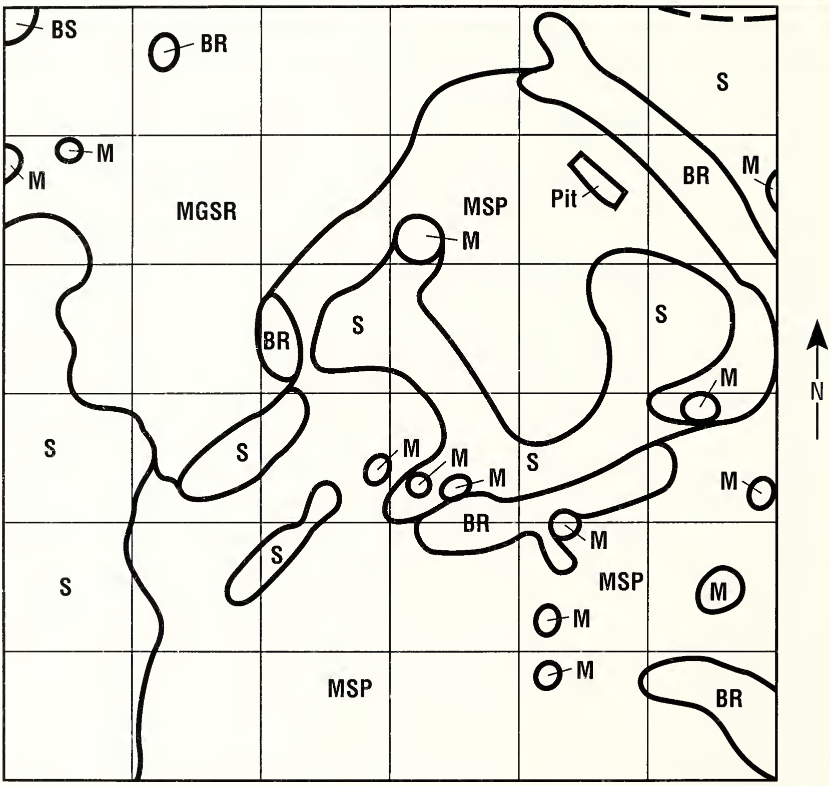
SAMPLED AS: LITHIC HAPLARGID
NATIONAL SOIL SURVEY LABORATORY; PEDON 89P 523, SAMPLES 89P2911-2916

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--
	(—— NH4OAC EXTRACTABLE BASES ——)							(—— CEC ——)										(—— PH ——)		
DEPTH (CM)	CA 5B5A 6N2E	MG 5B5A 602D	NA 5B5A 6P2B	K 5BA5 6Q2B	SUM BASES	ACID-ITY 6H5A	EXTR AL 6G9B	SUM CATS 5A3A	NH4-OAC 5A8B	BASES + AL 5A3B	AL SAT 5G1	-BASE SUM 5C3	SAT-NH4 OAC 5C1	CO3 AS CACO3 <2MM 6E1G	RES. OHMS /CM 8E1		COND. MMHOS /CM 81		CACL2 .01M 8C1F 1:2	H20 8C1F 1:1
	<——				MEQ / 100 G				——>	<——		PCT		——>						
0- 4	14.4	1.1	--	0.5	16.0			16.0	10.2			100	100	TR			0.08		7.6	8.1
4- 13		1.5	--	0.8					19.2			100	100	5			0.13		7.7	8.5
13- 23		1.2	0.1	0.5					19.9			100	100	10			0.13		7.7	8.3
23- 35		1.2	TR	0.4		--			19.6			100	100	18					7.6	8.1
35- 43																				
43- 50																				

ANALYSES: M= ALL ON SIEVED <2MM BASIS

Figure A-8 is a map of the area where the pedon was sampled and figure A-9 shows the landscape. The sample pedon is shown in figure A-10 and a close up of the ground surface near the pedon is shown in figure A-11.

FIGURE A-8



BR Bedrock
BS Bare Ground, 10% snakeweed
M Mesquite with coppice dune 30-50 cm high
MGSR Mixed grass, shrub
MSP Mixed shrub, pebbles
Pit S89NM051-001
S Sandy soil
— — Gully 30 cm deep and 75 cm wide

Sketch map of the area where the Lithic Haplargid mapping unit was described and sampled. Squares, 10m on edge.

FIGURE A-9

Landscape of the Lithic Haplargid mapping unit. Orientation is southwest to northeast. Shovel marks the sampling pit.

FIGURE A-10

Profile of Lithic Haplargid. Scale is in centimeters.

FIGURE A-11

Close-up photo of ground surface near pit for Lithic Haplargid. Yellow marker object in photo is 5x5x2 cm in size.

Soil Survey Manual Index

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